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**Foot Health of Asian Elephants (*Elephas maximus*)
in European Zoos**

Inaugural-Dissertation

zur Erlangung der Doktorwürde der
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Fußgesundheit Asiatischer Elefanten (*Elephas maximus*) in europäischen Zoos

Zusammenfassung

Fußerkrankungen stellen bei Elefanten in Zoos ein häufiges Problem dar. Durch persönliche Besuche von 69 europäischen Haltungen wurde die Fußgesundheit von 243 Asiatischen Elefanten (*Elephas maximus*) anhand von standardisierten Fotos von Nägeln und Fußsohlen untersucht. Hierbei wurden Pathologien (z.B. Nagelrisse, Abszesse), Fußpflegeaspekte (kleinere Veränderungen, die sich durch routinemäßige Fußpflege einfach beheben lassen) und die Struktur der Fußsohlen untersucht. Pathologien wurden in 35,6% aller untersuchten Nägel und Fußsohlen gefunden, wobei kleine Nagelrisse und angewachsene Nagelhäute am häufigsten auftraten. Drei (von 243) Elefanten zeigten keinerlei Pathologien. Die häufigsten Fußpflegeaspekte waren Fissuren in der Nagelsohle. Anhand des Anteils von Furchen in der Fußsohle wurde deren Struktur in vier Grade unterteilt, welche etwa gleich häufig auftraten. Zwischen der Verteilung der Fußpflegeaspekte und der Pathologien auf die einzelnen Nägel konnte über die Pearson-Korrelation kein signifikanter Zusammenhang aufgezeigt werden. Die Ergebnisse dieser Studie stellen die Grundlage für eine Querschnittsanalyse von möglichen Einflussfaktoren auf die Fußgesundheit dar. Zudem kann die Einteilung der Pathologien und Pflegeaspekte helfen, den Fußgesundheitsstatus von Zooelefanten langfristig zu protokollieren und anhand dieser Daten longitudinal den Einfluss von Veränderungen im allgemeinen und medizinischen Management zu untersuchen.

Stichworte: Asiatische Elefanten, *Elephas maximus*, Fußgesundheit, Pathologien

Foot health of Asian Elephants (*Elephas maximus*) in European zoos

Summary

Foot problems are a common concern in elephant husbandry. We investigated foot health of 243 Asian elephants (*Elephas maximus*) in 69 European institutions. During on-site visits, standardised pictures were taken of each elephant's nails and pads, which were analysed with respect to pathological lesions (i.e., nail cracks, abscesses), care issues (i.e., minor abnormalities, which are easily resolvable with routine foot work) and pad structure. Of all analysed nails and pads, 35.6% revealed varying degrees of pathological lesions, with minor nail cracks and overgrown cuticles with attachment to the nails being most frequently observed. Three (of 243) elephants did not show any pathological lesions in their feet. The most common issues requiring foot care were fissures in the nail sole. The pads' structure was categorised in four grades reflecting the percentage of surface marked by sulci, which occurred at nearly equal frequency. Pearson product moment correlations revealed no significant association between the frequency of care issues and pathological lesions per nail. Based on the results of this study, cross-sectional analyses of influencing factors on the foot health can be conducted. Furthermore, the characterisation of pathological lesions and care issues can be implemented in foot health protocols to monitor long-term responses to management and medical decisions in a more objective way and, ultimately, contribute to the overall well-being of elephants in human care.

Keywords: Asian elephants, *Elephas maximus*, foot health, pathological lesions

Foot health of Asian elephants (*Elephas maximus*) in European zoos

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From: jzwm@allentrack.net
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Date: 29 May 2019 at 03:27:51 CEST
To: mclauss@vetclinics.uzh.ch
Cc: miller@sun.ac.za
Reply-To: jzwm@allentrack.net

Dear Prof. Clauss,

I am pleased to accept "2018-0228R1", "Foot health of Asian elephants (*Elephas maximus*) in European zoos" for publication in the *Journal of Zoo and Wildlife Medicine*.

From your Associate Editor:

I appreciate the efforts that the authors have gone to respond to the reviewers' comments. I think that the new versions of Tables 2 and 3 provide additional information but am not sure that it warrants the extra space. I have made this recommendation to the editor and look forward to her feedback.

Thank you to all the authors for your work in revising this.

From your Editor: The Journal has the option of having supplemental digital content available in the on-line version of the manuscript. The plan is to expand this option to videos, additional figures, and (as is the case here) more comprehensive datasets. With your approval, I would like to use this option for your extended tables. I'll work with Allen Press to include a note in the printed version for the reader to view the on-line version for additional content.

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One final note: beginning with the June issue of JZWM, the cover of the Journal will now include a photo! If you would like one of your photos of your species considered for the cover, please send it to me. It must be an original photo for which you have the authority to allow reproduction. Please send only photos that are in the landscape orientation (unless you envision two side-by-side portrait style images)

Sincerely,

Nancy P. Lung, VMD, MS
Chief Editor, *Journal of Zoo and Wildlife Medicine*
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FOOT HEALTH OF ASIAN ELEPHANTS (*ELEPHAS MAXIMUS*) IN EUROPEAN ZOOS

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Abstract: Foot problems are a common concern in elephant husbandry. Studies on this topic with sample sizes above 100 animals have only been carried out in North America. We investigated foot health of 243 Asian elephants (*Elephas maximus*) in 69 European institutions. During on-site visits between August 2016 and July 2017, standardized pictures were taken of each elephant's nails and pads, which were analyzed with respect to pathological lesions (i.e., nail cracks, abscesses), care issues (i.e., minor abnormalities, which are easily resolvable with routine foot work) and pad structure. Of all analyzed nails and pads, 35.6% revealed varying degrees of pathological lesions, with minor nail cracks and overgrown cuticles with attachment to the nails being most frequently observed. The most lateral nail (N5) on both front feet demonstrated the highest percentage of pathological lesions, providing support to a separate study that the mean peak pressure of an elephant's foot occurs along the most lateral digits; however, this was not observed along the most lateral nail (N5) of the rear feet. Three (of 243) elephants did not show any pathological lesions in their feet. The most common issues requiring foot care were fissures in the nail sole. The structure of the pads was categorized in four grades reflecting the percentage of surface marked by sulci. These four grades occurred at nearly equal frequency. Pearson product moment correlations revealed no significant association between the frequency of care issues and pathological lesions per nail. Despite this finding, it may be prudent to implement husbandry protocols that could alleviate commonly observed pathological and care foot issues in captive Asian elephants. A standardized approach to evaluate elephant foot health will provide a more objective way to monitor responses to management and medical decisions and, ultimately, contribute to the overall wellbeing of elephants in human care.

Key words: Asian elephant, *Elephas maximus*, foot care, foot health, pathological lesions, pressure.

INTRODUCTION

Foot problems are a commonly reported concern in the care of captive elephants.^{3,13} There have been several previous studies investigating the status quo as well as the distribution of different pathological lesions within captive elephant populations (Table 1). Whereas North American investigations dealt with distinctly larger sample sizes, all studies within the European zoo elephant population considered less than 90 individuals. In most

studies, foot health was evaluated by local staff, which risks biasing results due to differing degrees of the evaluator's experience.^{9,11,14} Each study recorded a different set of pathological lesions of the elephant foot, complicating direct comparisons between results. However, nails were generally more frequently affected by pathological lesions than pads or interdigital tissues and the prevalence of any pathological lesion of feet ranged between 67.4% and 80.3%.

Three studies compared the prevalence of foot problems in Asian versus African elephants (*Elephas maximus*, *Loxodonta africana*).^{8,11,14} Two of them did not reveal a statistical significance when comparing the feet of both species in terms of lesions.^{8,14} In the third study, there was a small contribution to the statistical model indicating lower frequencies of pathological lesions of feet in African elephants, which however was explained by differing age structures.¹¹ In contrast to these scientific findings, anecdotal

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Table 1. Previous studies on elephant foot health in North American and European zoos.

Study	Sample size	Institutions	Considered pathological lesions	Most frequent pathological lesions in descending order ^a	Prevalence of any pathological lesion
Harris et al. (2008) ⁸	41 Asian elephants, 36 African elephants	13 UK zoos	Minor problems: uncomplicated nail cracks (not extended into cuticle), minor overgrowth of nails/cuticles/pads, minor injuries; Major problems: abscesses, infections, rot, complicated nail cracks, significant overgrowth of nails/cuticles/pads, significant injuries	Minor problem hind feet (39.3%), minor problem front feet (38.9%), major problem front feet (19.9%), major problem hind feet (8.0%)	80.3% (of all elephants)
Lewis et al. (2010) ¹¹	137 Asian elephants, 151 African elephants	78 North American zoos	Perionychia (lesion/sore between the nails), perionychia paired with nail softening/nail loss/vesicle formation, onychitis (infected nail), penetrating erosions, sloughed pads	Onychitis (16.7% of all facilities), perionychia with nail softening, perionychia	69.2% (of all facilities)
Haspeslagh et al. (2013) ⁹	87 Asian elephants	32 European zoos	Arthritis, blackleg (bacterial inflammation of sole with tissue necrosis), nail splitting, nail/sole overgrowth, abscesses, other (respondents named stiffness, torsion, uneven lateral wearing, osteoarthritis, paralysis)	Nail splitting (29.9%), abscesses (26.4%), nail/sole overgrowth (26.4%)	67.8% (of all elephants)
Miller et al. (2016) ¹⁴	215 Asian and African elephants, not listed individually	Unknown number of North American zoos	Toenails: cracks, defects, horn growth abnormalities; Foot pads: cracks, ulcerations, bruises, fissures, abscesses, or horn growth/sole abnormalities; Interdigital spaces: cracks, ulcerations, bruises, fissures, abscesses, or horn growth/sole abnormalities	Nail abnormalities (62.3%), interdigital space abnormalities (15.3%), pad abnormalities (8.8%)	67.4% (of all elephants)

^ainformation reflects the mode of presentation in the respective publication

reports from elephant keepers and experts suggested that Asian elephants require more frequent necessity of foot care especially concerning nails and cuticles because of a different foraging technique than their African counterparts.¹⁸ Furthermore, free-ranging Asian elephants live on more moist and yielding surfaces compared to African elephants, which may predispose Asian elephants to a higher susceptibility of foot problems in captivity, where harder substrates are commonly used to promote a clean environment.¹ The present study focuses on assessing the foot health and standardizing the pathological and care lesions of Asian elephants housed in European zoos.

To prevent foot problems, the implementation of routine foot care is a common approach, as it inhibits overgrowth and allows early detection of lesions.¹⁸ Characteristics of a foot in a good care condition are short and smooth cuticles, smooth and normally shaped nails, foot pads without excessive overgrowth, as well as interdigital spaces of at least one finger's width to allow drainage.¹⁸

Abnormally high/unnaturally distributed pressures on the feet are considered pathogenetic for several foot problems, e.g. nail cracks, abscesses and fluid pockets in the cuticles.^{18,19} In a previous study, peak pressures during walking were measured in seven regions of interest of the feet of five Asian elephants.¹⁶ Five of these regions of interest represented the nail areas. Taking anecdotal accounts of pathological lesions being most frequent in the middle and lateral nails (N3, N4 and N5), the authors concluded that high peak pressures were linked to pathological lesions of feet. However, due to the absence of detailed data, a statistical correlation of nail-specific peak pressures and prevalence of pathological lesions had not been performed in that study.

The aim of this study was to investigate the current status of foot health of Asian elephants in European zoos. The focus lay on analyzing a representative number of elephants by including all member institutions of the European Endangered Species Programme (EEP), and to collect the data in a comparable way by taking standardized pictures of the relevant structures of each foot. Furthermore, the co-occurrence of pathological lesions and care issues as well as of pathological lesions and peak pressures was to be analyzed.

Anatomical terms used in this article are presented in Figure 1.

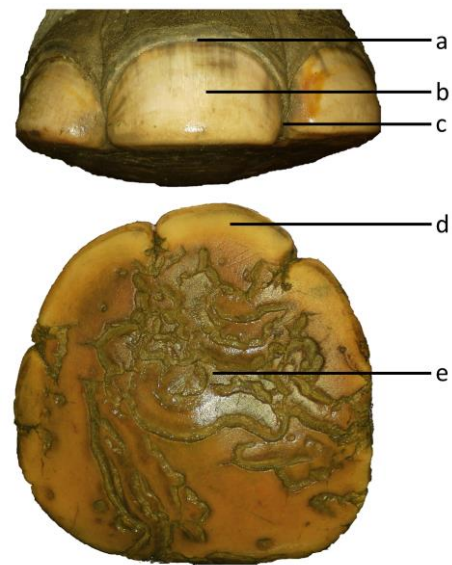


Figure 1. Pictures of a frontal and solar perspective of the foot of an Asian elephant (*Elephas maximus*) labeled with the anatomical terms used in this article, a = cuticle, b = nail surface, c = interdigital space, d = nail sole, e = pad.

MATERIALS AND METHODS

Ethics statement

The project was authorized by the management of each participating institution. Additionally, it was approved by the Elephant Taxon Advisory Group of the European Association of Zoos and Aquaria and the British and Irish Association of Zoos and Aquariums. The data collection was performed as part of routine training and therefore considered non-invasive.

Data collection

Between August 2016 and July 2017, 69 of 71 EEP-registered zoos were visited by one of two project veterinarians, who proceeded according to a standardized protocol. The remaining two institutions were not visited due to lack of response after contacting or insufficient training of the elephants. In 2016, the EEP population of Asian elephants consisted of 284 animals.⁴ Since only elephants aged five years or older at the time of visit were included, 243 individuals could be examined. Forty photographs were taken of each elephant: 18 nails (five per front and four

per hind foot) were pictured from a frontal and solar perspective and one photograph was taken of each pad. A Panasonic Lumix DMC-GF1 and Sony Cyber-Shot DSC-H9 were used, with supplemental lighting provided by a Neewer Flashgun FC100.

Analysis of foot pictures

Requirements for evaluation and approval of the pictures were full visibility and adequate lighting of the examined location. The photographs were processed in a *randomized* order, and the examiner was blinded to the elephant's identity. At first, all left front feet were analyzed, then all right front feet followed by left hind and right hind feet, avoiding consecutive analysis of the feet of the same elephant.

The pictures of all feet were analyzed for pathological lesions (Fig. 2), care issues (i.e. minor alterations easily resolvable by foot care, Fig. 3) and the structure of the pad (Fig. 4). Based on the experiences made while photographing and following previous descriptions, especially by the Elephant Welfare Group (EWG), ten different pathological lesions were defined and categorized in three severity grades: mild, moderate, or severe (Fig. 2).^{12,18,19,24} Nail cracks not reaching the cuticles/ not exposing underlying tissues/ without inflammation, and overgrown cuticles with attachment to the nail were categorized as *mild* lesions, which follows the EWG-classification.¹² In contrast to that, overgrowth of nails/soles/pads and cuticles without attachment to the nails, as well as disfigured nails were not considered to be pathological lesions but were classified as care issues (Fig. 3) due to their lesser degree of severity.

Solar horn defects exposing underlying tissues, major nail cracks (reaching the cuticles, exposing underlying tissues or with inflammation), fluid pockets in the cuticles and soft tissue areas in the pad were categorized as *moderate* pathological lesions. Solar horn defects may lead to ascending infections.⁵ Another term for major cracks reaching from sole to cuticle is “split nail”, which can become chronic by damaging the germinal tissue or developing abscesses and are therefore described as serious foot problem.^{18,19,24} Fluid pockets in the cuticles presumably contain accumulated fluid of sweat glands, sometimes causing pressure and

pain.^{18,19} Soft tissue in the pad was identified in the pictures as lighter areas, probably resulting from excessive trimming.¹⁸

Purulent discharge, altered tissues underneath the cuticles paired with solar horn defects (implying the defects spread underneath the entire nail) and substantial apical nail lesions exposing underlying tissues were classified as *severe* lesions. Sterile nail abscesses may develop from devitalization in deeper tissue layers and usually rupture at the cuticle or nail sole.¹⁸ Therefore, altered tissues on both locations imply a more serious underlying process. Substantial apical nail lesions may damage germinal tissue, leading to serious interference with the growth of new, healthy nail tissue. If there was more than one pathological lesion on the same nail or pad, the worst lesion determined the severity grade.

Minor foot defects, defined as conditions easily resolvable with routine foot work, were categorized as “care issues” (Fig. 3). These included frayed cuticles without attachment to the nail, superficially fissured nail soles, abnormal/disfigured nail surfaces or horn rings (recorded per nail), frayed pad edges and spaces between the nails narrower than one finger's width (recorded per foot). To analyze them on an individual basis, all care issues were counted, resulting in a theoretical maximum of 17 per front foot (frayed cuticle, fissures and disfigurements on five nails, frayed pad edge and too narrow interdigital spaces) and of 14 per hind foot because of the reduced number of nails. Consequently, the theoretical maximum of care issues per elephant is 62.

As another concern of foot care without evident link to pathological processes, the pad structure was categorized in four grades reflecting the degree of marking by sulci. To determine them, the percentage of coverage with sulci was visually estimated, using reference pictures in which these proportions were actually measured by planimetry (Fig. 4).

Descriptive statistics

The prevalence (including their 95% confidence interval) of the different pathological lesions, considered separately and summarized as any pathological lesion, were calculated on different levels including 1. individual nails and pads, 2. entire foot, and 3. whole elephant. On the level of particular nails and pads, the frequencies were calculated for


Severity	Pathologic finding	Example picture
Mild	Minor nail cracks (do not reach the cuticles, do not expose underlying tissues, are not inflamed)	
	Overgrown cuticles, attached to the nail	
Moderate	Defects of solar nail horn, exposing underlying tissues	
	Major nail cracks (reach the cuticles or exposing underlying tissues or inflamed)	
	Fluid pockets in cuticles	
	Soft tissue areas in the pad, characterized by a lighter area	
Severe	Purulent discharges in the nail area	
	Purulent discharges in the pad	
	Altered nail tissues underneath the cuticle and solar horn defect (which implies that the defect spreads underneath the entire nail)	 
	Substantial apical nail lesion, exposing underlying tissues	

Figure 2. Description and example pictures of pathologic findings in the feet of captive Asian elephants (*Elephas maximus*) according to their severity.




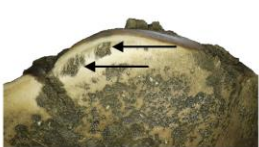



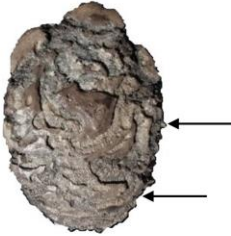


Description of care issue	Picture without care issue	Picture with care issue
Frayed cuticle, not attached to the nail		
Fissured nail sole		
Disfigured nail surface or superficial horn rings		
Frayed edge of the pad		
Interdigital spaces in a foot narrower than one finger's width		

Figure 3. Description of care issues in the feet of captive Asian elephants (*Elephas maximus*) with example pictures of the relevant structure when affected or not affected.

each structure and summed up for all nails and pads. On the foot level, a foot was counted as positive regarding a pathological lesion if at least one nail or pad was affected. The units “front feet” and “hind feet” result from the summation of the prevalences of the two respective feet. On an elephant level, an elephant was counted as positive if a pathological lesion occurred on at least one foot. The same calculations were carried out for the prevalence of care issues and pad structure grades.

Analysis of co-occurrences

The co-occurrence of pathological lesions and care issues was tested using Pearson’s correlation for the prevalences of any

pathological lesion and any care issue on the different nails. Using data from an unrelated study on pressure distribution in elephant feet¹⁵, peak pressures during walking [kPa] were correlated to the prevalence of pathological lesions of feet [%] observed in this study. Extrapolating data from that publication, mean pressure values [kPa] of all available elephants were correlated with the prevalence of any pathological lesion, minor nail cracks, attached cuticles, major nail cracks and solar horn defects [%] for each nail. Since the remaining pathological lesions did not occur in all nails, they were not included. Additionally, the prevalence of pathological lesions in front and hind feet were compared to the corresponding pressures.¹⁶





Grade	Percentage of surface covered with sulci	Reference picture
1	< 15%	
2	15 – 29%	
3	30 – 44%	
4	≥ 45%	

Figure 4. Classification of the pad structure in the feet of captive Asian elephants (*Elephas maximus*) according to their estimated percentage of coverage with sulci by the means of reference pictures.

RESULTS

Prevalence and distribution of pathological lesions

Pictures that met the inclusion criteria were available for 4034 nails and 914 pads (Table 2). A complete set of pictures was present for 204 elephants. The remaining elephants did not have the necessary level of training to allow photographing all nails and pads, or the enclosures did not provide the required access.

Of all 4948 analyzed structures, 64.5% did not reveal any pathological lesion (Fig. 5). The remaining 35.5% of structures contained pathological lesions that were classified as being mild (19.7%), moderate (15.1%), or severe (0.8%) (Fig. 5). Whereas 43.6% of the nails showed lesions, only 0.7% of the pads were affected (Table 2). Nails were most frequently affected by minor cracks (19.0%), attached cuticles (13.1%) and solar horn

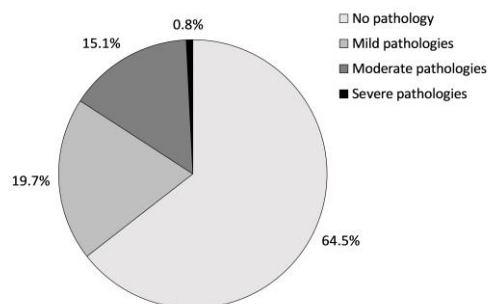


Figure 5. Distribution of pathological lesions in the feet of captive Asian elephants (*Elephas maximus*) according to their severity considering all analyzable structures ($n_{\text{total}} = 4948$ with $n_{\text{nails}} = 4034$ and $n_{\text{pads}} = 914$).

defects (12.4%). Least frequent were fluid pockets (<0.1%) and apical lesions (0.1%). Soft pads occurred more often than purulent pads (0.5% / 0.1%).

Pathological lesions of nails were most frequent in the most lateral nails (N5) of the front feet (Fig. 6). The middle nails (N2, N3 and N4) were affected nearly equally. Of the front feet, the most medial nails (N1) were least affected, whereas of the hind feet, the lateral nails (N5) showed the lowest frequency of pathological lesions.

As displayed in Table 2, the right front feet showed the highest prevalence of pathological lesions (91.6%), followed by left front feet (86.5%), left hind feet (82.3%) and right hind feet (75.4%). Most lesions were more frequent in front compared to hind feet, except for fluid pockets in the cuticles, which occurred at equal frequency, and soft pads as well as apical nail lesions, which were slightly more frequent in hind feet.

Of the 204 elephants, 1.5% had four feet without any pathological lesion, whereas the remaining 98.5% expressed at least one pathologic lesion (Fig. 7). On average, 7.9 of 22 structures (18 nails and 4 pads) were affected. In the majority of elephants, four to twelve structures were affected. The anonymized original data is available upon request.

Prevalence and distribution of care issues

Care issues were assessed in 4034 nails, 891 pads and interdigital spaces were evaluated in 914 feet (Table 3). The number of considered pads regarding care issues is lower than the 914 pads that were used to assess

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Table 2. Absolute and relative frequencies and confidence intervals of pathological lesions in the feet of captive Asian elephants (*Elephas maximus*). Detailed data, e.g. on particular nails, in supplemental digital online content available.

Unit	n	Any pathology	Minor nail crack	Attached cuticle	Solar horn defect	Major nail crack	Fluid pockets	Soft pad	Purulent nail	Purulent pad	Altered tissue in cuticle and sole	Apical nail lesion
Nails	4034	1757	768	529	500	276	2		10		26	5
		43.6%	19.0%	13.1%	12.4%	6.8%	<0.1%		0.2%		0.6%	0.1%
		42.0% -	17.9% -	12.1% -	11.4% -	6.1% -	<0.1% -		0.1% -		0.4% -	<0.1% -
		45.1%	20.3%	14.2%	13.4%	7.7%	0.2%		0.5%		0.9%	0.3%
Pads	914	6						5		1		
		0.7%						0.5%		0.1%		
		0.3% -						0.2% -		<0.1% -		
		1.5%						1.3%		0.7%		
Left front foot	222	192	139	81	76	61	0	0	2	0	8	2
		86.5%	62.6%	36.5%	34.2%	27.5%	0%	0%	0.9%	0%	3.6%	0.9%
		81.3% -	56.1% -	30.4% -	28.3% -	22.0% -	0.0% -	0.0% -	<0.1% -	0.0% -	1.7% -	<0.1% -
		90.4%	68.7%	43.0%	40.7%	33.7%	1.5%	1.5%	3.4%	1.5%	7.1%	3.4%
Right front foot	227	208	136	116	89	65	1	2	3	1	10	0
		91.6%	59.9%	51.1%	39.2%	28.6%	0.4%	0.9%	1.3%	0.4%	4.4%	0%
		87.2% -	53.4% -	44.6% -	33.1% -	23.1% -	0.0% -	<0.1%	0.3% -	0.0% -	2.3% -	0.0% -
		94.6%	66.1%	57.5%	45.7%	34.8%	2.7%	- 3.4%	4.0%	2.7%	8.0%	1.4%
Left hind foot	215	177	108	67	78	58	0	3	1	0	1	2
		82.3%	50.2%	31.2%	36.3%	27.0%	0%	1.4%	0.5%	0%	0.5%	0.9%
		76.6% -	43.6% -	25.3% -	30.1% -	21.5% -	0.0% -	<0.1%	0.0% -	0.0% -	0.0% -	<0.1% -
		86.9%	56.9%	37.6%	42.9%	33.3%	1.5%	- 4.2%	2.9%	1.5%	2.9%	3.5%
Right hind foot	224	169	96	62	79	44	1	0	3	0	5	1
		75.4%	42.9%	27.7%	35.3%	19.6%	0.4%	0%	1.3%	0%	2.2%	0.4%
		69.4% -	36.5% -	22.2% -	29.3% -	15.0% -	0.0% -	0.0% -	0.3% -	0.0% -	0.8% -	0.0% -
		80.6%	49.4%	33.9%	41.7%	25.4%	2.7%	1.4%	4.0%	1.4%	5.3%	2.7%
Elephants	204	201	178	147	142	120	2	4	7	1	15	4
		98.5%	87.3%	72.1%	69.6%	58.8%	1.0%	2.0%	3.4%	0.5%	7.4%	2.0%
		95.6% -	81.9% -	65.5% -	63.0% -	52.0% -	<0.1% -	0.6% -	1.5% -	0.0% -	4.4% -	0.6% -
		99.7%	91.2%	77.8%	75.5%	65.4%	3.7%	5.1%	7.0%	3.0%	11.9%	5.1%

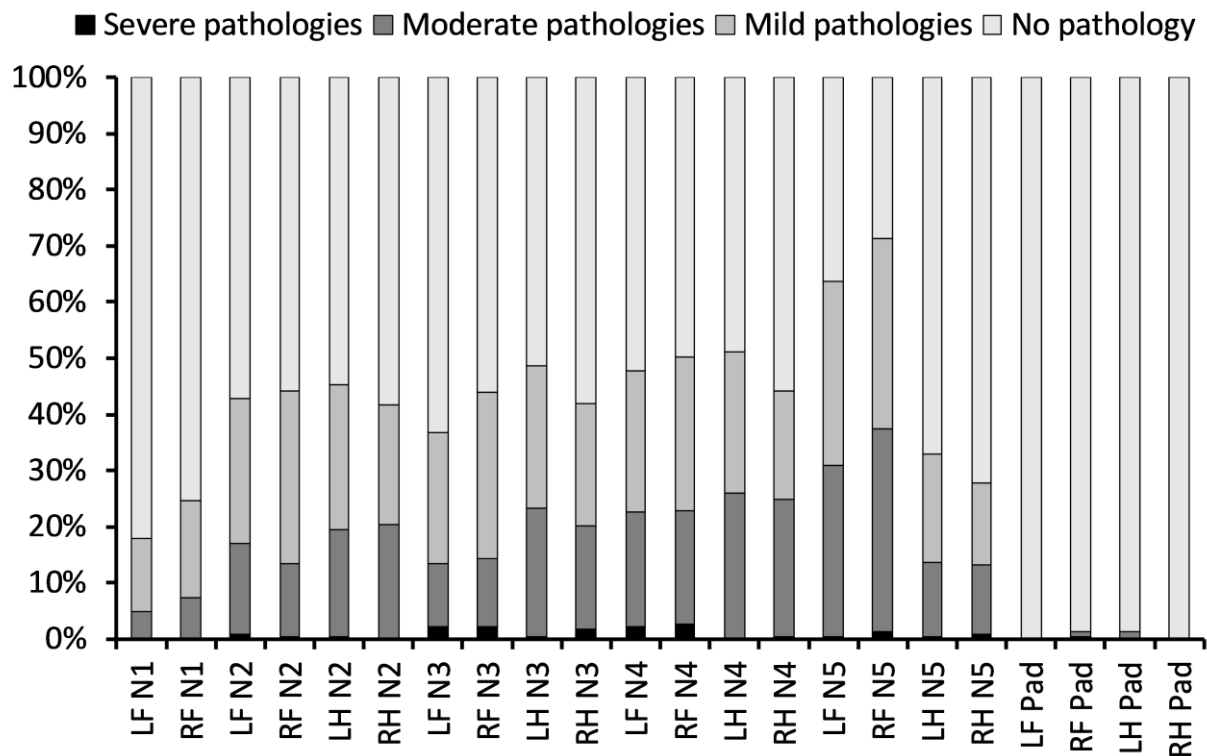


Figure 6. Distribution of pathological lesions in particular nails and pads of captive Asian elephants (*Elephas maximus*) according to their severity, LF = left front foot, RF = right front foot, LH = left hind foot, RH = right hind foot, Nx = nail x (numbered from medial to lateral).

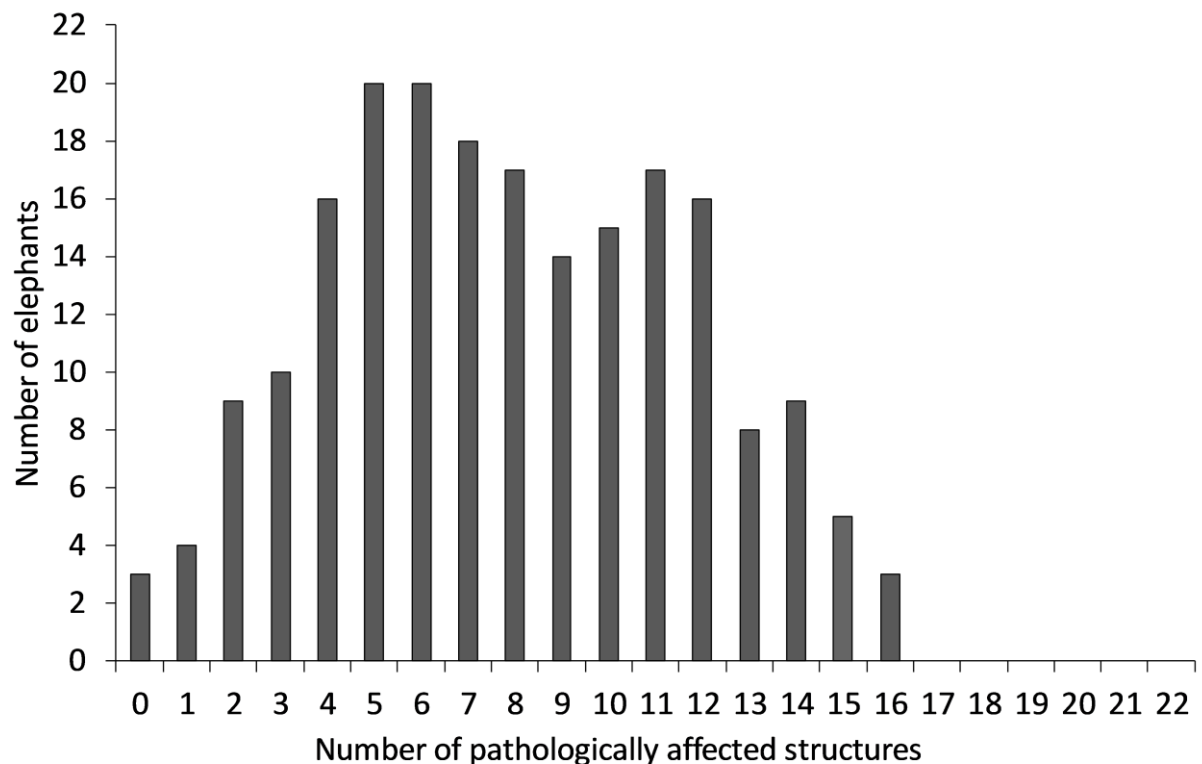


Figure 7. Distribution of the number of pathologically affected structures (nails and pads) per elephant in captive Asian elephants (*Elephas maximus*) (n = 204).

Table 3. Absolute and relative frequencies and confidence intervals of care issues in the feet of captive Asian elephants (*Elephas maximus*). Detailed data, e.g. on particular nails, in supplemental digital online content available.

Unit	n	Any care issue	Cuticle	Fissures	Surface nail	Edge of pad	Interdigital space
Nails	4034	1795	490	1248	360		
		44.5%	12.1%	30.9%	8.9%		
		43.0% - 46.0%	11.2% - 13.2%	29.5% - 32.4%	8.1% - 9.8%		
Pads	891	54				54	
		6.1%				6.1%	
		4.7% - 7.8%				4.7% - 7.8%	
Interdigital spaces	914	44					44
		4.8%					4.8%
		3.6% - 6.4%					3.6% - 6.4%
Left front foot	209	173	75	137	79	2	13
		82.8%	35.9%	65.6%	37.8%	1.0%	6.2%
		77.0% - 87.3%	29.7% - 42.6%	58.9% - 71.7%	31.5% - 44.5%	<0.1% - 3.6%	3.6% - 10.4%
Right front foot	222	199	66	160	87	3	25
		89.6%	29.7%	72.1%	39.2%	1.4%	11.3%
		84.9% - 93.1%	24.1% - 36.1%	65.8% - 77.6%	33.0% - 45.7%	<0.1% - 4.1%	7.7% - 16.1%
Left hind foot	213	170	60	135	49	13	0
		79.8%	28.2%	63.4%	23.0%	6.1%	0%
		73.9% - 84.7%	22.5% - 34.6%	56.7% - 69.6%	17.8% - 29.1%	3.5% - 10.3%	0.0% - 1.5%
Right hind foot	222	182	79	150	43	36	0
		82.0%	35.6%	67.6%	19.4%	16.2%	0%
		76.4% - 86.5%	29.6% - 42.1%	61.1% - 73.4%	14.7% - 25.1%	11.9% - 21.7%	0.0% - 1.5%
Elephants	191	187	114	174	113	33	28
		97.9%	59.7%	91.1%	59.2%	17.3%	14.7%
		94.6% - 99.4%	52.6% - 66.4%	86.1% - 94.4%	52.1% - 65.9%	12.5% - 23.3%	10.3% - 20.4%

pathological lesions (Table 2) since sometimes, due to the position of the foot, only the pad's surface was sufficiently visible, but not its edge. In 191 elephants, all care issues could be evaluated (Table 3).

Nearly half of all nails (44.5%) showed care issues (Table 3). Most frequent were fissured nail soles (30.9%) followed by overgrown cuticles (12.1%), and disfigured nails or horn rings (8.9%). In 4.8% of the feet, the interdigital spaces were less than one finger wide and 6.1% of pads showed a frayed edge. In descending order, most care issues were found on the right front (89.6%), left front (82.8%), right hind (82.0%) and least

frequently in the left hind feet (79.8%). All care issues occurred more frequently in the front feet, except for frayed edges of the pad, which were nearly ten times more frequent in hind than in front feet (11.3% / 1.2%).

Of the 191 elephants 2.1% showed no care issue (Fig. 8). On average, an elephant had 9.5 care issues. The highest number was 30 (theoretical maximum: 62).

Distribution of pad grades

Pad grades were evaluated based on the guidelines presented in Figure 4 for 917 feet: 232 left front, 233 right front, 224 left hind and

228 right hind feet (Table 4). The numbers differ between the feet because sometimes, pictures could not be taken of all four feet. For left front feet, Grade 1 was most frequent (27.6%). The highest frequency in right front and left hind feet was found for Grade 2 (30.5% / 29.0%) and for right hind feet, it was Grade 4 (29.4%). Considering all feet, the distribution ranged between 23.3% (Grade 3) and 27.9% (Grade 2). Following summation of the grades of elephants with four pad pictures ($n = 222$), the totals of eleven and four occurred most frequently ($n_{11} = 24$, $n_4 = 23$). The theoretical and actual range for the summed pad grades is 4-16 (Fig. 9).

Analysis of co-occurrences

Comparing prevalences of pathological lesions and care issues on the different nails showed no significant correlation ($p = 0.567$). According to data of the previously mentioned study¹⁵, mean peak pressures are highest on the middle nails (N3) of the left hind and left front feet (297.6 kPa / 282.0 kPa) and the lateral and middle nails (N5, N3) of the right front feet (285.6 kPa / 253.1 kPa). Comparing mean peak pressures of all nails of that study¹⁵ and the prevalence of pathological lesions of the corresponding nails of the present study,

significant correlations were found for attached cuticles ($r = 0.57$, $p = 0.013$) and major nail cracks ($r = 0.53$, $p = 0.022$). Highest mean peak pressures and frequencies of attached cuticles were found in the middle and the lateral nails (N3, N5) of the right front feet. Both lateral nails (N5) of the front feet showed the highest mean peak pressures and frequencies of major cracks. Minor cracks, solar horn defects and any pathological lesion were not significantly correlated to mean peak pressures ($p \geq 0.05$).

DISCUSSION

Analysis of foot pictures

Contrary to previous studies, foot health was not assessed at the time of in-person evaluation of the elephant but was performed upon review of standardized pictures. This allows a thorough analysis of all available feet, which might be difficult in direct evaluation if the elephant is nervous or not appropriately trained. For the elephants without a complete set of pictures, a proper direct examination would not have been feasible either. The person evaluating the photographs was one of two project veterinarians who also took the

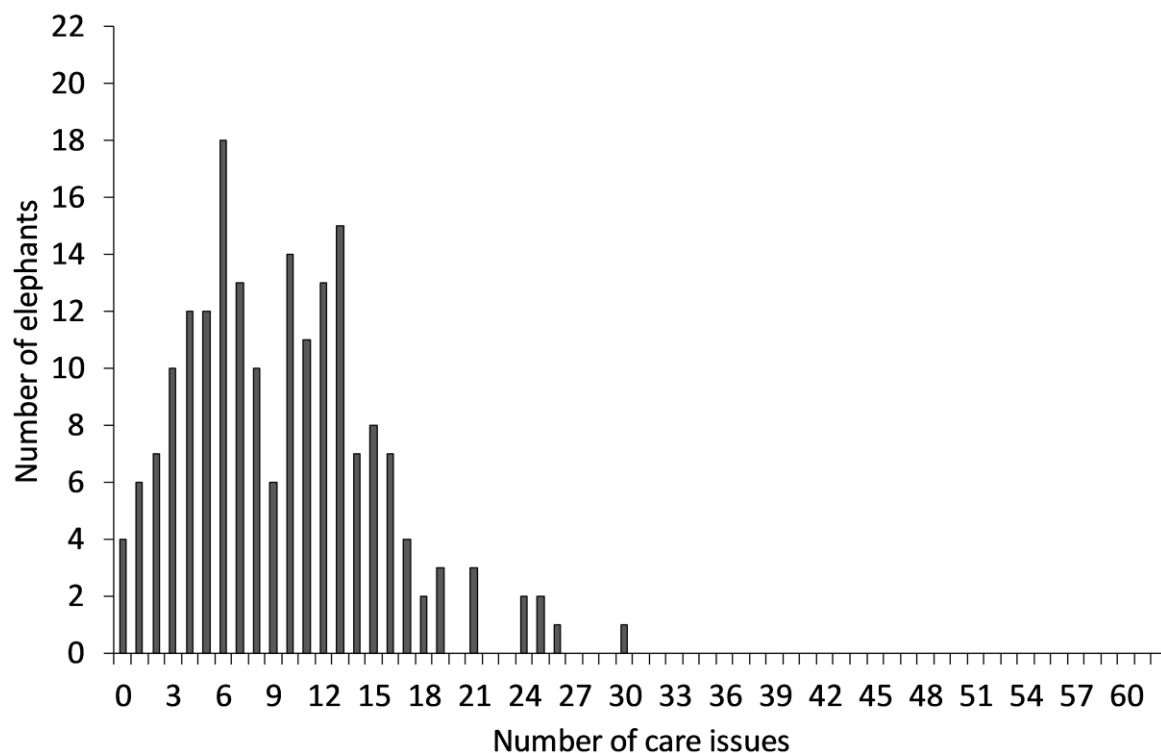
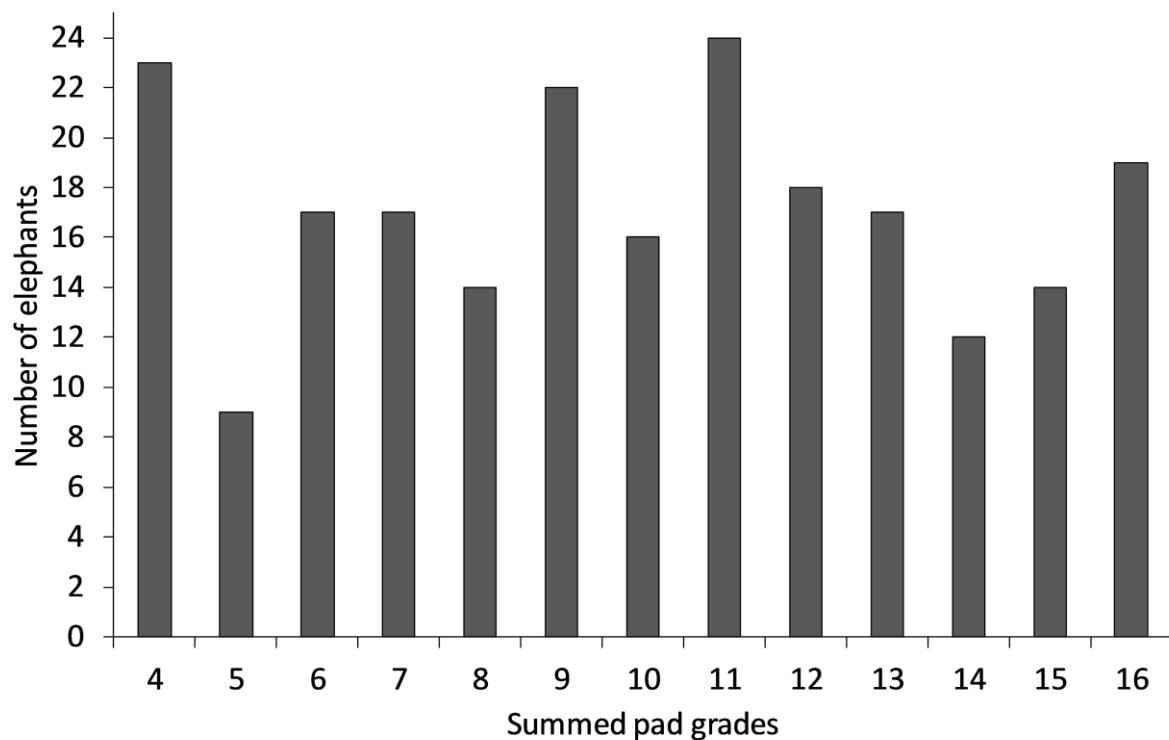


Figure 8. Distribution of the number of care issues per elephant in captive Asian elephants (*Elephas maximus*) ($n = 191$).

Table 4. Frequencies (in % [95% confidence intervals]) of surface grades in foot pads of captive Asian elephants (*Elephas maximus*).

Grade	All feet (n = 917)	Left front foot (n = 232)	Right front foot (n = 233)	Left hind foot (n = 224)	Right hind foot (n = 228)
1	23.7 [21.0-26.5]	27.6 [22.2-33.7]	19.3 [14.7-24.9]	25.0 [19.8-31.1]	22.8 [17.8-28.7]
2	27.9 [25.1-30.9]	24.6 [19.5-30.5]	30.5 [24.9-36.7]	29.0 [23.5-35.3]	27.6 [22.2-33.8]
3	23.3 [20.7-26.2]	24.6 [19.5-30.5]	25.8 [20.5-31.7]	22.8 [17.7-28.7]	20.2 [15.5-25.9]
4	25.1 [22.4-28.0]	23.3 [18.3-29.1]	24.5 [19.4-30.4]	23.2 [18.1-29.2]	29.4 [23.8-35.6]

**Figure 9.** Distribution of summed pad grades in captive Asian elephants (*Elephas maximus*) (n = 222).

photographs, theoretically, allowing the potential recognition of individuals. Since the analysis included more than 8,000 photographs showing foot structures in a standardized format, and feet in randomized order, recognition was rather unlikely. Using example pictures and accurate descriptions, pathological lesions and care issues were defined as precisely as possible. Nevertheless, the distinction between minor and major cracks considering the exposition of underlying tissues and between fissures in the nail sole and more profoundly extending solar horn defects was sometimes difficult. To

minimize unequal evaluation, all pictures were processed by the same person. In most previous studies, foot health was evaluated by local zoo staff which risks biasing results through different individual experience.^{9,11,14} For future studies, which compare or summarize similar health conditions, an evaluation of all individuals by the same person is therefore recommended. Alternatively, a requirement would be to supply the examining persons with example pictures and detailed descriptions of the defined pathological lesions to generate comparable data.

Prevalence of pathological lesions

This study evaluated foot health among a high percentage (82.9%) of the captive Asian elephant population in European zoos. The prevalence of pathological lesions per individual elephant in this report (98.5%) was higher than in previous European studies (67.8% and 80.3% in UK zoos).^{8,9} The increased prevalence is presumably due to the higher sensitivity of evaluating lesions using standardized pictures compared to direct evaluations, as opposed to reflecting a general deterioration of foot health within the captive population. Mild lesions such as minor cracks and attached cuticles, which occurred most frequently, might be considered normal in elephants.⁸ Nevertheless, there was also a high frequency of moderate lesions such as solar horn defects (69.6%) and major cracks (58.8%) (Table 2). Since it is questionable whether an elephant should be considered ill if, for example, only one or two structures (whether nails, pads or both) are only mildly affected, it might be more appropriate to evaluate prevalence on the level of these structures, separately. When analyzing pathological lesions on a structural level [i.e., based on all evaluated nails (n = 4034) and pads (n = 914)], as opposed to an individual elephant level, the prevalence decreases to 35.5%. Although previous studies have evaluated pathological lesions, variations in data parameters and categories has precluded comparisons with these findings.

The frequency of pathological lesions of feet in free-ranging elephants is unknown due to difficulties in collecting data.⁶ For captive elephants in India, prevalences of 49.1% and 84% have been reported.^{17,20} Although these elephants lived in their natural habitat, husbandry conditions were often not comparable to the natural environment, since many elephants considered in these studies were kept in simple enclosures on mud or concrete flooring, used for logging or tourism activities or were regularly chained.^{17,20} Therefore, the natural occurrence of foot lesions and the extent of the influence of inadequate husbandry cannot be derived from this data. Further investigations on free-ranging Asian elephants are required to explore their foot health status.

Reasons for the most common foot pathologies

Most common pathological lesions were nail cracks, attached cuticles and solar horn defects. Nail cracks are suspected to develop from unnatural pressures on the nail. Possible causes for abnormal pressure are hard surfaces (especially when lying down), nail overgrowth, trauma, being overweight, repetitive stereotypic movement and leg malalignment.^{18,19,24} Similar to the hoof mechanism in horses, the elephant's whole foot expands when bearing weight and contracts after the weight is lifted.^{2,23} Measuring the area under the elephant's foot when standing on three versus four feet showed that the area increases with higher pressures, which verifies the transformations within the foot.²¹ During walking, there is a continuous expansion and contraction; thus, minor nail cracks easily extend further to major cracks.²³ An adequate foot care regimen may prevent cracks from growing larger by minimizing pressure and displacing forces. Therefore, the affected nail needs to be shortened with the smaller part of the split nail being trimmed even more, so that the two parts of the nail do not shift against each other.¹⁸

The reason for Asian elephants' tendency to develop overgrown/attached cuticle is unknown. Possibly, the intense use of the feet while grazing might be associated with a more continuous nail and cuticle growth. But since several keepers stated that in some Asian elephants, cuticle work is not necessary, the existence of further causes, e.g. genetic ones, is possible. Using their trunk, some elephants tend to manipulate the overgrown cuticle injuring the skin and generating an entry for microorganisms.

A potential pathogenesis of nail infections is the embedding of foreign bodies in the nail, which leads to a blackening and necrosis of the area.¹⁰ This condition reflects a solar horn defect. Aside from foreign bodies, inadequate foot care or previously weakened nail tissue because of poor nutrition, poor general health or unsanitary substrates predisposes the nail to infections.^{5,7}

Prevalence of care issues

The recording of care issues allowed the consideration of minor foot modifications, being insufficient to be regarded pathological

but still anatomically abnormal. Similar to the interpretation of pathological lesions, it might be more appropriate to look at the prevalence of care issues on the level of particular structures (nails, pads and interdigital spaces) (32.4%) than on the individual elephant level (97.9%). Here, similar frequencies of care issues and pathological lesions with overlapping confidence intervals concerning nail changes (CI_{care} : 43.0% - 46.0%, CI_{patho} : 42.0% - 45.1%), were found. The number of care issues might depend on the general husbandry conditions as well as the time since the last foot care procedure. Foot care in a herd is usually carried out in a continuous process (e.g. one foot per day) and not all feet are cared for at the same time. Therefore, it was not possible to capture all feet at the same stage after foot care due to relatively short visits to each facility. If data was recorded directly after foot care, the aim would be to have no care issues. Because data was collected at a random date, sometimes even shortly before the next scheduled foot care, a certain percentage of care issues was to be expected. This should not be a matter of concern regarding foot health as long as an adequate foot care is carried out on a regular basis, assuming that a well-cared foot allows early detection of problems and prevents deterioration.^{18,22}

Distribution of pad grades

The foot pads of wild elephants appear rough with deep grooves and cracks, which are nevertheless in balance of growth and wear through walking great distances.¹⁸ Captivity might either lead to an excessive pad growth due to a lack of exercise, or to corrosion through the frequent exposure to urine and feces.¹⁸ The four grades were nearly equally distributed with overlapping confidence intervals. Suggested main influences on the pad structure are flooring and activity determining the natural wear, as well as trimming during foot care. Opinions amongst elephant keepers differed, whether pads should be trimmed to a smooth surface or left rough with sulci. Whereas a smooth surface avoids missing foreign bodies during foot care, a rough one provides natural protection and might also help reducing pressures on the nails by exceeding their level. Peak pressure measurements with differently structured pads would be necessary to verify this. In captive

elephants, foot pads were found to be half as thick as in wild elephants, which implies that not trimming pads might be preferable.¹ Nevertheless, based on the collected data, it cannot be determined which pad structure is best for foot health in captive elephants. An analysis on an elephant basis, which correlates the general foot health with the pad structure might provide further insights. To do so, a foot scoring system suitable for epidemiologic approaches is required.

Distribution of pathological lesions of nails and correlation to care issues and peak pressures

Using different methods, previous studies found higher pressures in elephants' front compared to hind feet: during walking, there was a difference of 5% when using statistical parametric mapping and a difference of 73% when comparing peak pressures.¹⁶ Similarly, elephants standing on all four feet showed 45-59% lower pressures in their hind feet.²¹ The prevalence of any pathological lesion found in this study was 10.3% higher in front than in hind feet with non-overlapping confidence intervals (CI_{front} : 85.8% - 91.7%, CI_{hind} : 74.7% - 82.4%), supporting a potential association between pressure and pathological lesions. However, the higher prevalence in front feet might also be due to the higher number of potentially affected structures by having one additional nail. When calculating the percentage of pathologically lesioned nails and pads for all front versus all hind feet, the prevalence is still higher in front feet with non-overlapping confidence intervals (CI_{front} : 35.5% - 39.1%, CI_{hind} : 31.5% - 35.4%), but the difference is not that considerable anymore (37.3% / 33.4%).

To explain the distribution of pathological lesions to the different nails, a combined influence of pressure distribution and care status of the nails can be considered. The high frequency of pathological lesions in the lateral nail, N5, of both front feet might be explained by deficient foot care. Performing foot care is extremely physically demanding. During observations of routine trimming at multiple facilities, keepers commonly began working on the big, obvious middle nails N2, N3, N4 of the front feet. When it comes to N5, the strength of the person doing the foot trim might begin to fail. Additionally, this nail was observed to be often difficult to reach if the

elephant is treated in protected contact. But with that explanation, why was the lowest frequency found for the front feet's medial nails N1, which are also difficult to reach? For these nails, it can be assumed that being smaller and bearing less weight might prevent them from being affected by problems. Whether these are the real causes for the difference in prevalence remains to be elucidated.

As there was no significant correlation between the distribution of care issues and pathological lesions, the hypothetical explanation for the high frequency of pathological lesions in N5 could not be confirmed. Other suggested reasons for problems with the lateral nails are sleeping on hard surfaces in lying position and higher pressures, but both of which would affect front and hind feet.^{16,18}

The relation of peak pressures and pathological lesions reveals significantly more attached cuticles and major nail cracks for nails with higher peak pressures. This was true for the middle and lateral nail (N3 and N5) of the right front foot regarding attached cuticles and for the lateral nails (N5) of both front feet regarding major nail cracks. For major nail cracks, abnormal pressures were already discussed as part of the pathogenesis, so these findings support this assumption. Overgrown or attached cuticles were so far not linked to high pressures, but since the pathogenesis is unknown, high pressures are worth considering besides other factors like genetics or nutrition. The results of the correlations to peak pressures should be regarded with caution, because pressure values were only available for a small sample size (five elephants) of young age (mean: 12.2 years).¹⁵ This might limit the comparability to our sample population (mean age: 29.7 years). Additionally, except for the two youngest elephants, pressure values were not available for all feet which distorts the mean pressures because heavier elephants show higher peak pressures.¹⁶ Abnormal pressures as pathogenesis for foot problems currently form a basic idea of preventive foot care. Therefore, their contribution should be further analyzed, comparing pressure values and pathological lesions of the same sample population while also examining the influence of foot care and different substrates. By implementing a standardized approach to evaluating foot health in captive Asian elephants, data between

studies can be easily compared, and eventually used, to advance the overall wellbeing of this species in human care.

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**Theory of medical scoring systems and a practical method
to evaluate Asian elephant (*Elephas maximus*) foot health
in European zoos**

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Theory of medical scoring systems and a practical method to evaluate Asian elephant (*Elephas maximus*) foot health in European zoos

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Abstract

To evaluate an individual health or disease status, there are several established models in human and veterinary medicine. Many of these do not seem suitable for further epidemiological research aimed at discovering underlying influential factors. As a case example for score development and choice, the present study analyses different approaches towards scoring the foot health of Asian elephants (*Elephas maximus*) living in European facilities. Sum scores with varying degree of detail, and without or with a weighting method, were compared using descriptive statistics, i.e. kurtosis, skewness, Shannon entropy, total redundancy, their maximum and their actual ranges. With increasing score complexity, a higher level of differentiation was reached. In parallel, the distribution of score frequencies in the population shifted systematically: with the least complex scoring model the pattern indicated a severely unhealthy population with an opposite skew to a hypothetically healthy population, whereas the most complex scoring model indicated a mildly affected population with a skew corresponding to that expected for a healthy population. We propose the latter, in form of the Particularised Severity Score (ParSev), which accounts for every nail and pad individually and weights the subscores by squaring, as the most relevant score for further investigations, either in assessing changes within an elephant population over time, or correlating foot health in epidemiological studies to potentially influencing factors. Our results emphasize the relevance of choosing appropriate scoring models for welfare associated evaluations, due to implications for the applicability as well as the perceived welfare status of the test population.

Keywords: animal welfare - Asian elephant - epidemiology - foot health - weighting factor - scoring system

Introduction

Foot health of Asian elephants (Elephas maximus)

With the elephant being the heaviest terrestrial mammal on the planet, its foot is one of the most important load-bearing structures in the animal kingdom. According to a personal communication of Prof. D. K. Lahiri-Choudhury cited in Csuti et al. (2001), about 50% of elephants in an Asian working camp are affected by foot problems. Sarma et al. (2012) came to a similar conclusions with half of their investigated population of Asian elephant in India suffering from foot pathologies, whereas

Ramanathan and Mallapur (2008) found that 74.1% of their respective sample population showed pad fissures and 46.9% nail cracks of any sort. Under zoo conditions, foot health, especially in Asian elephants (*Elephas maximus*), is a widely discussed and difficult-to-assess management issue (Csuti et al. 2001, Fowler 2006). To investigate the status quo of Asian elephant foot health in Europe, we determined the prevalence of foot pathologies (Wendler et al. 2019). Several other studies have investigated links between the prevalence of foot health conditions and husbandry factors (Harris et al. 2008, Haspeslagh et al. 2013, Lewis et al. 2010, Miller et al. 2016), using different

approaches to assess and evaluate foot health status. Due to the differences between those approaches, they depict varying status of elephant foot health with prevalences ranging from 67.4% to over 80%. Therefore, meaningful conclusions regarding it cannot be easily made. For epidemiological evaluations as such, a quantitative score as an objective measurement of foot health is preferred, yet there is no commonly accepted way how to develop such a score. Here, we present and discuss different approaches to quantify health status in general and their consequence for the perception of a population's health. The Asian elephant population currently living in European zoos presents a suitable example.

Evaluating health and disease status

Since the evaluation and prediction of a pathologic process is important and, at the same time, rather difficult, point-based risk scoring models are popular (Austin et al. 2016). In creating such a model, a series of questions needs to be answered. One of the most important ones is what method of score calculation to use. One possibility is to follow a “maximum” concept, by exclusively scoring according to the most severe condition, neglecting all other occurring conditions. For instance, triage scoring systems follow such an approach in cases of having to assess several patients at once in critical situations (Benson et al. 1996). In such a system, a patient, is categorised as “immediate” and is treated without delay, as soon as a predefined condition occurs (Apnea or breathing rate $>30/\text{min}$ or severe bleeding or unconsciousness). A similar “maximum” concept has been used by the Elephant Welfare Group (Masters 2013). This model assigns the value of its most severe pathology at any location (nail, pad or cuticle) to an elephant, according to a grading system (0-3). In other words, an individual without any lesions except for a single severe one (single subscore of 3) would be assigned the same total score (3) as an elephant suffering from severe lesions at all possible locations (multiple subscores of 3).

Most of the established models in human medicine, however, go for a sum-based evaluation such as the Glasgow Coma Scale (Jones 1979) or the APGAR score for newborn health (Apgar and James 1962). In these

protocols, certain factors are assigned a value, and all values are added up to a final score, which is used to rank the overall condition. For example, the APGAR score examines respiratory effort, heart rate, muscle tone, skin colour, and reflexes with point values from 0 (bad) to 2 (healthy), leading to a score range from 0 to 10. The newborn is categorised as either ‘life at risk’ (<3), ‘at risk’ (4-6) or ‘normal’ (>7). Such a system has, at least theoretically, evident limitations. For instance, there is the theoretical eventuality of a newborn with acute apnea, but normal values in all other categories and subsequently a score of 8, which would be considered normal, despite of life-threatening acute apnea. With respect to elephant feet, a sum score would sum up the scores given to each individual foot, according to the method applied by Harris et al. (2008). Similar limitations apply in such a system, as an elephant with three healthy feet (a score of 0) and one foot considered severely affected (a score of 3) would have a lower total score ($0+0+0+3=3$) compared to an elephant with one minor alteration on each foot ($1+1+1+1=4$). In practice, misclassifications due to an atypical distribution of subscores may differ in their likelihood between scoring systems, reflecting the interdependency of the variables. In the APGAR example, it is extremely unlikely to find an apneic newborn with good muscle tone and skin colour. However, in elephants, uneven distributions of pathologies across individual feet appear more frequently (Wendler et al. 2019).

According to Avila et al. (2015), a “formative model” is a concept that consist of several, independently changing, observable factors, as in foot health, which are added up to a final score. Using this approach, a simple sum does not reflect different severities of pathologic changes. Therefore, Bollen and Bauldry (2011) or Avila et al. (2015) emphasize the requirement for a weighting factor in such models. An example that includes a weighting factor is the APACHE model (Acute Physiology and Chronic Health Evaluation), which evaluates certain values of temperature, heart rate, age, and others to predict the likelihood of mortality of a patient (Knaus et al. 1985, Knaus et al. 1991, Zimmerman et al. 1998). The advantage in developing this model lies in the possibility of verifying the prediction by comparing results

with the actual outcome. Thus, it is possible for the revised scores (APACHE II to IV) to adjust weighting factors. Another example is the SAPS model (Simplified Acute Physiology Score) (Le Gall et al. 1993). In contrast to these models, the introduction of weighting factors appears difficult in a onetime, status-quo oriented assessment of elephant foot health without the possibility to evaluate the individual outcome at a later stage.

Another important question in developing a score is whether extreme values (low or high) describe a healthy status, or whether the healthy optimum is represented in the middle of the score range. In body condition scores (BCS), the optimum is typically located in the middle of the score range, with both ends being suboptimal, indicating either cachexia or obesity (Edmonson et al. 1989). In other systems, certain factors add up to either a healthy status, as in the AGPAR Score (Apgar and James 1962), or a pathologic status, as in the score used for foot dermatitis in chicken (Ekstrand et al. 1994). This results in different expectations for a population's score distributions. In Figure 1, score A would be an example for a model that adds up to a healthy status, as in the APGAR model, with the majority of scored individuals in a relatively healthy sample population showing high values. Score B outlines a model that adds up to a pathologic status, as in the foot dermatitis score of chicken. Therefore, the majority of a healthy population has a low score. Score C represents a model where the middle score is favorable, with decreasing numbers of individuals towards low and high scores, displaying a normal distribution. In the case of elephant foot health, resembling a formative model, with several independent components, an approach similar to score B seems appropriate.

In order to represent the actual health status of a population in epidemiological studies, a sufficiently high resolution of a score, which allows distinguishing between mildly and severely affected individuals, is important.

For this purpose, we developed a scoring protocol considering each pathology and all possible locations (each individual nail, each individual pad → 22 locations) similar to the existing foot evaluation of flamingo feet (Nielsen et al. 2010, Wyss et al. 2013). Conditions were classified based on the severity

grading of the Elephant Welfare Group's evaluation (Masters 2013) and modified according to Wendler et al. (2019). Non-pathologic care conditions and the pad's surface structure were recorded separately to all pathologies.

The intention for this study was to calculate and compare different scoring approaches in assessing an elephant's foot health, in order to determine the best model regarding epidemiological analysis.

Material and methods

Data collection

Wendler et al. (2019) investigated the foot health of Asian elephants in 69 institutions registered in the European Endangered Species Programme (EEP). The foot health status of all individuals aged 5 or older were photographically recorded. This age limit was decided because of the presumed lack of training of animals younger than 5 years in most institutions. To apply foot scoring systems, information about all considered structures are necessary, which were available for 204 of the examined 243 elephants regarding foot pathologies. For restrictions in training status or enclosure accessibility it was not possible to generate a complete set of photographs for all individual elephants. Evaluation of the care status was possible in 191 elephants and of the pad's surface in 222 elephants. The care status was recorded by the use of a care score which sums up the number of non-pathologic alterations that can theoretically be removed during a single foot care procedure. Additionally, foot measurements were performed to record the length, width and circumference of each foot, using a soft measuring tape.

Data evaluation

All pathologic findings regarding nails and pads were categorised in three severity grades (1 = mild, 2 = moderate, 3 = severe pathology), whereas healthy structures were scored as 0 (Wendler et al. 2019). Wendler et al. (2019) describe minor nail cracks and overgrown cuticle as mild, solar horn defects and major nail cracks, as well as fluid pockets in the cuticle and soft tissue areas of the pad as moderate. Purulent discharge of the nail or the pad, altered nail tissue of the cuticle combined with a solar horn

defect, and substantial nail lesions are considered the most severe conditions. According to the applied protocol, the rater noted all present pathologies for every location (five nails per front foot, four nails per hind foot, and four pads resulting in 22 locations). The score for each location derived from the worst occurring pathology at this specific location leading to a total of 4^{22} theoretically possible combinations. The resulting data was subsequently interpreted according to a series of scoring protocols.

Calculation of foot health scores

Based on the considerations outlined in the introduction, a “Maximum Score” was calculated, which attributes the worst scored value of all locations as a total score to an elephant, as in Masters (2013) [range: 0 - 3]. Corresponding to Harris et al. (2008) a “Sum Score”, based on the maximum subscores of the four feet was evaluated as well [range: 0 - 12]. Because a limited amount of combinations can reduce the information of a scoring model (Howell et al. 2007), the number of considered locations was increased for a “Particularised Sum Score”(ParSum) [range: 0 - 66] that sums up information from every investigated location (i.e. not feet, but all nails and pads). In order to avoid the loss of information due to a simple summing up of all subscores as mentioned by Avila et al. (2015), subsequent protocols used squaring as a weighting factor to quantitatively maintain the information that a severity grade of 2 is worse than two severity grades of 1, comparably to the calculation of the Injury Severity Score (ISS) (Baker et al. 1974). This was done, for every foot’s value in the “Severity Score” [range: 0 - 36], and again for every location’s value in the “Particularised Severity Score” (ParSev) [range: 0 - 198] (Table 1). An exemplary calculation for all scores using two fictitious elephants is presented in Table 2.

Additional scores: Care and Pad Score

All conditions that were graded non-pathologic due to the theoretical possibility of being cared for in a single pedicure procedure were considered as a Care Score by simple addition. It involves three conditions per nail (frayed cuticles, solar fissures, disfigured nail surfaces) and two per pad/foot (frayed pad edges, narrow interdigital spaces between the nails), resulting

in a range from 0 – 62 in an Asian elephant. Those conditions were recorded for a later analysis of potential correlations between care status and pathologic scores. Since there was a considerable visual difference between the majority of pads, the surface structure of all evaluated pads was considered via a Pad Score which summed up the value of all pads (Wendler et al. 2019). The single pad’s value describes the estimated proportion of so called “sulci” or furrows in the surface ($1 < 15\%$, $2 = 15\% - 29\%$, $3 = 30\% - 44\%$, $4 \geq 45\%$) [range: 4 -16] (Table 1). Note that all pathologic changes of the pad are considered in the foot health scores.

Statistical evaluation

For each of the five foot health scores examined here, the underlying theoretical distribution was calculated, using Matlab R2018a (Moler 1984). This was done under the assumption, that all possible 4^{22} individual score combinations occurred equally frequent and displayed in all graphs as ‘equal distribution’. The actual distributions of the foot health scores were characterised by descriptive statistics (incl. median and interpercentile range; skewness, kurtosis and their corresponding 95% confidence intervals; and Kolmogorov Smirnov Test for normal distribution).

Skewness describes whether the data distribution resembles a normal distribution with equally diminishing slopes towards the left and the right side, or whether the distribution is shifted to one end of the range (Kim 2013). By this definition, a ‘sided’ score in which the healthy status equals a score of 0 will have a right skew (skewness > 0) if the investigated population is healthy. In Figure 1, the distribution of Score A demonstrates such a right or positive skew. In contrast, score B is negatively or left skewed (skewness < 0).

Kurtosis values describe the position of peaks and outliers compared to a normal distribution. Distributions peaking higher than expected based on a normal distribution have positive kurtosis values (leptokurtic), while negative values indicate an evenly spread (‘flat’) distribution with less outliers and slopes (platykurtic). For example, if the BCS (in a system ranging from 1-10) of a population showed a very high number of individuals at any particular score (e.g. an ideal score of 5), with

very few individuals having other scores, it would have a positive kurtosis. If, in contrast, scores of 3-7 all occurred at similar frequency in the population, it would have a negative kurtosis. In a 'sided' score, one would expect a high kurtosis if one would assume both, a healthy or a particularly unhealthy population.

As a measure of information content and score character redundancy, Shannon entropy and total redundancy were calculated. The Shannon entropy (Shannon et al. 1949) is used in mathematical communication theory to assess the amount of information per character in a certain data source. It uses the maximal amount and frequency of each available data point (in our case subscores) and results in a number with bits per character as unit. As an example, the Latin alphabet has 26 letters. Due to their asymmetric occurrence, the alphabet shows an entropy of 4.0629 bits per character in contrast to the maximum of 4.7004 (which would result, if all characters appeared equally). For the whole alphabet, this difference can be calculated to a total redundancy of 4.08 characters, i.e. an alphabet with 22 characters would theoretically suffice for the information typically provided. A similar approach can help to discover the number of unnecessary characters in scoring models.

To test whether scores show a significant difference to one another, in regards of ranking order, Wilcoxon-tests were performed, and Spearman rank correlations were employed to test the correlation between scores.

Linear foot measurements were regressed against body mass to yield allometric equations in the form of $\text{lenght} = a\text{BM}^b$, with BM=body mass, and an expected geometric exponent of 0.33 (because a length measure should geometrically scale with a volume or mass measure to the power of 0.33) (Clauss and Hummel 2005). These models were calculated as linear regressions after log transformation ($\log \text{length} = \log a + b \log \text{BM}$). We tested whether foot health or care status influenced these allometries by adding the different scores as factors in the regression.

For all statistical calculations R software version 3.4.1. (Ihaka and Gentleman 1993) or SPSS version 23 (IBM 1968) were used. The significance level was set at 0.05.

Results

None of the investigated scores resulted in a normally distributed population. There were significant differences between all scores by Wilcoxon-tests ($p < 0.001$), which means that the ranking of animals by their foot health status differed significantly. Despite the notable difference in the ranking of individuals, there were significant correlations between all foot health scores ($p < 0.05$) (Table 3; Figure 2), indicating that the significant difference of the Wilcoxon-tests was not caused by an inversion of ranking of individuals between different scoring systems, but by the fact that in the less differentiated tests, animals had the same score that were further differentiated in the more detailed scoring systems. The Pad Score did not correlate significantly with the Maximum Score, the Particularised Sum Score or the Care Score.

The Maximum Score, the Sum Score, and the Severity Score used their full possible range (suggesting that the worst possible cases actually occurred in the population), whereas the particularised scores did not. Regarding the general distribution of all assigned scores, distinct differences between most of the models were evident. For example, kurtosis values ranged from -0.162 (Particularised Sum Score) to 1.993 (Maximum Score). The health score skewness ranged from a left skewed distribution of -0.551 (Maximum Score, indicating a population tending towards the 'unhealthy' part of the spectrum) to a clear right skewed distribution of 1.064 (Particularised Severity Score, indicating a population tending towards the 'healthy' part of the spectrum). Calculated according to the achieved maximum, the Shannon entropy ranged from 1.174 (Maximum) to 5.305 (ParSev). A further computation of total redundancy shows values from 2.086 [70.4%] (ParSum) to 10.446 [5.2%] score characters (ParSev), with the ParSev being the scoring model that used the least amount of available scoring characters (69/198) (Table 4).

All anatomical measurements met the expectations of a geometric allometric scaling, with an exponent of 0.33 in the 95% confidence interval of the body mass exponent (Table 5). No foot health score had any significant effects on these relationships. The Care and Pad Score, however, were related to length and width

allometries, with higher scores associated with higher length or width measures in several cases.

Discussion

Note that our scores only describe the current status of foot health in Asian elephants in Europe. There is need to put this data into context taking potentially influencing factors like age or husbandry conditions into account, but the main aim of the present contribution is a discussion of the effect of designing or choosing a particular scoring system.

Our study demonstrates the challenges of designing an appropriate health score system and ensuring implications for data interpretation. Rules for scoring an individual animal - resembling the typical unit for epidemiological analysis of a population - can lead to drastically different conclusions for the scored population depending on the applied protocol. While our results consistently indicate that the Asian elephant population in Europe shows a certain degree of impaired foot health, its perceived degree varies dramatically between the individual scoring systems. The least complex system indicates a severely affected population, with a distribution skewed in the opposite direction of what would be expected for a healthy population, and with a frequency pattern pinpointing a nearly equal distribution of each potential combination of pathologies. In contrast the most complex (i.e., most differentiated) scoring system displays a mildly affected population, with a distribution skewed towards the direction assumed for a healthy population, and a frequency pattern close to that of a hypothetically healthy population. In addition, the more complex system allows a higher differentiation between individual elephants with a wider spread of subscores (0-69), in contrast to the least complex system with scores ranging from 0-3. Moreover, Wilcoxon-tests prove a significant difference in ranking order between all scores since scoring systems with fewer subscores summarise individuals in the same score that otherwise would vary in ranking order (Fig. 2).

The Maximum Score suggests a rather dire health situation. More than two thirds of all elephants are assigned with the second worst total score of two, which results in a negative,

left skewed distribution (-0.551) (Table 4). This constellation evokes the impression that most of the sample population is subject to at least moderate pathologic changes in their foot health (Figure 3). This is a result of a strong tendency towards higher scores expressed by this protocol, as indicated by its theoretical equal distribution. Because of the maximum calculation method, the higher scores are by far more likely when assuming an equal distribution than lower scores (Score 2: 0.18%, score 3: 99.82%). The actual distribution's kurtosis value of 1.993 hints at a very steep frequency distribution, which is a result of the accumulation of score 2 individuals. This accumulation also triggers the interpercentile range of 0, which suggests that most of the scored individuals are assigned with score values extremely close to one another. Shannon entropy indicates that 2.8 characters of the 4 available are theoretically redundant (i.e., 70.4% of the score range).

In conclusion, the Maximum Score is completely blurred by its focus on the total score of 2, and for this reason a rather limited model for our analysis. Restrictions were obvious regarding maximum range, actual range, calculation method and animal-to-animal distinction. We predict this scoring system to have very little value for epidemiological studies on the influence of various factors on foot health.

The slightly more complex Sum Score shows small improvements (Figure 4). Here the maximum range is reached as well, and a large part of the population is depicted with moderate foot health issues (56.9% with scores over 6). But as with the Maximum Score, similar calculation limitations exist. In an equal distribution scenario, 98.7% of cases are assigned a value of 9 or higher. However, the added dimension of feet-wise addition pushes the actual distribution towards a more normal one and towards the 'healthy population' at the same time, resulting in a neutral skew of -0.281 with a 95% confidence interval (CI) from -0.614 to 0.052. The same is true for the kurtosis CI of -0.800 to 0.528. An interpercentile range of 3 showed an increased spread in the single value distribution compared to the maximum model. The Shannon entropy of 3.083 is increased and the redundancy with 2.604 (20.0% of the score range) less than in the Maximum Score, but still

renders one fifth of all subscores redundant (Table 4).

The Severity Score is characterized by implementing the squaring weight factor for all foot values, which helps to achieve a higher differentiated 'pathologic representation'. The equal distribution scenario shows certain restrictions due to the mathematical foundation (Figure 5). Due to the limit of four squarable locations, eight of the 36 score values cannot possibly be computed, and the most frequent combinations (Scores over 26: 93.6%) still lead to a left skew in the theoretical distribution. Although the actual distribution shows a shift towards a hypothetical 'healthy population', the maximum range is still reached. The 'squaring peaks' are reflected by a right skew of 0.654, combined with a high kurtosis of 1.589 which describes a high occurrence of outliers compared to the normal distribution. An interpercentile range of 10 shows a wide spread of subscores, being part of the reason why Shannon entropy is increased to a value of 3.879. The model's calculation limitation become evident in a redundancy value of 7.322 (19.8% of the score range), which means that still one fifth of the subscores are redundant, similar to the Sum Score (Table 4).

To enhance accuracy, the Particularised Sum Score (Figure 6) considered 22 scoring locations in an Asian elephant. Without the suppressing effect of summarising particular structures by considering only the foot (Sum Score) or even the elephant level (Maximum Score), the equal distribution scenario of this approach shows a well-balanced normal distribution. Since the healthy conditions with scores of 0 are here as likely as pathologies valued with 3, an even curve without any accumulating effect as in prior scoring models is present. The actual distribution indicates a trend towards the theoretically healthy distribution and is therefore right skewed (0.464), but with a low kurtosis of -0.162 (CI: -0.826 - 0.502). The maximum range is not reached (range: 0-29) and the interpercentile range of 8 shows a fairly even spread of values according to the achieved range. Due to the larger maximum and actual range compared to earlier scores, Shannon entropy is increased to 4.532 and redundancy therefore lowered to 2.086 (3.1% of the score range) (Table 4). Nevertheless, the ParSum Score lacks

a weighting factor to stress the severity of moderate and severe lesions.

On the basis of summing every considered location combined with a squaring weighting factor, the ParSev's equal distribution scenario resembles a normal distribution as seen in the ParSum model (Figure 7). The actual distribution shows the highest right skew (1.064) of all analysed scores and again a squaring-based peaky kurtosis (1.615) comparable to the Severity model. Similar to the ParSum model, the maximum range of 198 was not reached (actual range: 0 - 69) and the occurring subscores seem to be relatively even spread with an interpercentile range of 15. The Shannon entropy value of 5.305 shows a further increase in amount of information per character, whereas the ParSev's redundancy is increased (10.446) (Table 4). However, this value corresponds to only 5.2% of the score range.

The analysis of all models showed that the general assessment of a population shifts as scoring models become more detailed and more individual factors (here, nails and pads) are included. Similarly, in the APACHE score development, an addition of more variables from APACHE I with 34 factors to APACHE IV with 142 factors resulted in an additional gain of information (Vincent and Moreno 2010).

Additional scores

The Care Score showed a low kurtosis of 0.561 (CI: -0.125 - 1.247) and a right skewed distribution of 0.707 (Table 4). Furthermore, it does not reach its theoretical maximum range and therefore seems to describe a relatively well-cared-for population. We did not see the necessity to assess care conditions employing different severity grades. Consequently, there is no need to implement weighting and it seems appropriate to just summarise the lack of certain care procedures per elephant. Doing so resulted in a Shannon entropy value of 4.352 and a relatively low redundancy of 3.824 (6.1% of maximum range). The Care Score was significantly correlated to all foot health scores (Table 3), suggesting that the level of foot care applied to an individual elephant is associated with its foot health status.

The Pad Score had a strong negative kurtosis of -1.078 and no skewed distribution (0.002). The theoretical maximum was reached

and the subscores are evenly distributed. The score achieved entropy values of 3.657 and a very low redundancy of 0.153 (1.2% of maximum range) (Table 4). This is the result of the values' even spread without outliers, rendering a very small percentage of characters redundant. A judgment whether any score is more natural or healthy does not seem reasonable, and no emphasis in the distribution is manifest. In particular, there was no significant correlation between the Pad Score and the Care Score, and neither between the Pad Score and two of the five foot health scores (Table 3). The latter leads to the suggestion that the Pad Score has limited relevance for elephant foot health.

Both non-pathologic scores seem to have an influence on the scaling of elephant feet in relation to their body mass (Table 5). This is explained by the fact that less cared-for nails and pads are usually overgrown and thus larger due to the excess skin and nail substance.

Conclusion

This study's intention was to calculate and compare different scoring models, regarding their ability to be used as an epidemiological evaluation tool. The most basic Maximum Score model describes a severely affected population whereas the ParSev displays a dramatically different picture. The implementation of a weighting factor in the most differentiated models allows distinguishing animals with few severe lesions from those with many minor pathologic changes. We consider this feature practically relevant.

Another important aspect of scoring models is their ability to reflect changes over time. Evidently more differentiated scores are more suited to indicate exacerbation or improvement over time and are recommended when trying to assess effects of modifications to animal husbandry. As Miller et al. (2016) found it difficult to assess severity and foot problems from veterinary records, our ParSev system provides a numeric value that reflects representative data about an elephant's foot health. This can help to track the foot health development of individual animals and whole populations.

In everyday routine, the model has some disadvantages regarding its overall practicability. Transferring a finding of concern in an elephant

into a score is not something required for the management of individual animals, were a detailed description of the specific foot conditions, and its continuous monitoring and communication in non-abstract terms, is far more important. Scores are rather required for epidemiological status or development surveys of whole populations, for example to assess the average state of welfare, or correlations with other husbandry conditions. While it would be desirable to do such surveys on a frequent basis, for example to record the foot health of the European zoo population on a yearly basis and thus monitor development over time, this represents an enormous workload that probably cannot be expected to be performed on a routine basis. Most likely, a practical solution is to have certain individuals, such as master students, perform such surveys at larger time intervals. Since there is no outcome the foot scores are trying to predict, as in models for organ function (Multiple Organ Dysfunction Score, Logistic Organ Dysfunction Score or Sepsis-related Organ Failure Assessment Score) (Pettilä et al. 2002) or patient mortality (APACHE scores), a direct comparison and validation of the accuracy of the scores (to describe a certain outcome) is not feasible. Nevertheless, the model presents a useful tool to quantitatively assess and monitor the foot health status of elephants in a cross-sectional as well as longitudinal manner.

Animal welfare implications

More detailed scoring protocols suggest a higher health standard in the investigated population than is indicated by the less detailed scores, which has implications for the perception of zoo elephant husbandry. Therefore, the choice of a scoring model could be considered also a political one, depending on the agenda of the person or organisation that initiates the scoring. In general, applying the model with the highest degree of differentiation seems adequate from a position that aims at understanding a situation in detail. This holds true until the point of becoming too complex, where even though a larger variety of factors are considered only limited additional information is gained (Champion et al. 1980). In the case of Asian elephant foot health in Europe, the ParSev Score is the most robust model, which covers all occurring combination of pathologies. However,

it also depicts the zoo elephant population in the most favorable foot health condition compared to other models. This finding is in accordance with the prevalences of individual foot pathologies previously reported for the population under consideration (Wendler et al. 2019). While 98.5% of all examined elephants showed some kind of pathology, only 35.6% of all structures were affected, and only 2.2% of lesions were considered severe. This situation would be poorly reflected by the Maximum Score, which implies a heavily affected population. In conclusion, the ParSev model is a pertinent score to enable an objective analysis of foot health in Asian elephants.

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Table 1 Description and calculation of all foot scoring systems used in the present study

Score	Description	Formula [Range]
Maximum	Total score is the most severe finding in all locations	$\text{score}_{\text{max}}$ [0-3]
Sum	Total score is the sum of the four foot scores	$\text{score}_{\text{LF}} + \text{score}_{\text{RF}} + \text{score}_{\text{LH}} + \text{score}_{\text{RH}}$ [0-12]
Severity	Total score is the sum of its four squared foot scores	$(\text{score}_{\text{LF}})^2 + (\text{score}_{\text{RF}})^2 + (\text{score}_{\text{LH}})^2 + (\text{score}_{\text{RH}})^2$ [0-36]
Particularised Sum	Total score is the sum of all nail and pad scores	$\text{score}_{\text{RFN1}} + \text{score}_{\text{RFN2}} + \text{score}_{\text{RFN3}} \dots \text{etc}$ [0-66]
Particularised Severity	Total score is the sum of its separately squared nail and pad scores	$(\text{N1}^2 + \text{N2}^2 + \text{N3}^2 + \text{N4}^2 + \text{N5}^2 + \text{pad}^2)$ for all feet [0-198]
Care	Total score is the sum of all care conditions	[0-62]
Pad	Total score is the sum of the four individual pad scores	$\text{pad}_{\text{LF}} + \text{pad}_{\text{RF}} + \text{pad}_{\text{LH}} + \text{pad}_{\text{RH}}$ [4-16]

max = maximum; RF = right front foot; LF = left front foot; RH = right hind foot; LH = left hind foot; N = nail

Table 2 Exemplary score calculation for two elephants with different foot health status

Foot	Location	Elephant A	Elephant B
Left front	N1	0	1
	N2	0	1
	N3	0	2
	N4	1	0
	N5	1	0
	Pad	0	0
Right front	N1	1	0
	N2	1	3
	N3	0	2
	N4	0	3
	N5	2	1
	Pad	0	0
Left hind	N2	0	0
	N3	0	0
	N4	2	0
	N5	1	3
	Pad	0	0
Right hind	N2	0	0
	N3	0	0
	N4	0	0
	N5	3	1
	Pad	0	0
Scores			
	Maximum	3	3
	Sum	8	9
	ParSum	12	17
	Severity	18	23
	ParSev	22	39

N = nail, score 0 = no pathology, score 1 = minor pathology, score 2 = moderate pathology, score 3 = severe pathology

Depending on the score model used, the perception of individual health varies. The Maximum and Sum models evaluate elephant A and B as equally affected, whereas the ParSum, the Severity and especially the ParSev models show that elephant B is more severely affected.

Table 3. Correlation between all elephant foot scores using normalized values.in combination with Spearman's correlation coefficient ρ (triangle on the right) and results of Wilcoxon-tests to compare the ranking of individual animals between two scoring systems (triangle on the left)

[illegible]

Table 4 Descriptive statistics for the different foot scoring methods

	Maximum Score	Sum Score	Severity Score	ParSum Score	ParSev Score	Care Score	Pad Score
Total score range	0 – 3	0 – 12	0 – 36	0 – 66	0 – 198	0 – 62	4 – 16
N	204	204	204	204	204	191	222
Kolmogorov-Smirnov- Test	<0.001	<0.001	<0.001	0.003	<0.001	<0.001	<0.001
Median	2	6	10	11	17	9	10
[interpercentile range]	[0]	[3]	[10]	[8]	[15]	[8]	[6]
(min – max)	(0-3)	(0-12)	(0-36)	(0-29)	(0-69)	(0-30)	(4-16)
Kurtosis	1.993	-0.136	1.589	-0.162	1.615	0.561	-1.078
[CI]	[1.332-2.660]	[-0.800-0.528]	[0.925-2.253]	[-0.826-0.502]	[0.951-2.279]	[-0.125-1.247]	[-1.715- -0.441]
Skewness	-0.551	-0.281	0.654	0.464	1.064	0.707	0.002
[CI]	[-0.884- -0.218]	[-0.614-0.052]	[0.321-0.987]	[0.131-0.797]	[0.731-1.397]	[0.368-1.046]	[-0.317-0.321]
Shannon entropy [bits/character]	1.174	3.083	3.879	4.532	5.305	4.352	3.657
Total redundancy [character]	2.817	2.604	7.322	2.086	10.446	3.824	0.153
(% of character range)	(70.4%)	(20.0%)	(19.8%)	(3.1%)	(5.2%)	(6.1%)	(1.2%)
Summary statement	Severely affected population	Moderately affected population	Moderately affected population	Mildly affected population	Mildly affected population	/	/

Kolmogorov-Smirnov-Test: Tests for normal distribution

Kurtosis: Describes occurrence of outliers in comparison to normal distribution (0 = normal distributed; <0 more evenly distributed than normal; >0 distribution with higher peaks than normal)

Skewness: Describes emphasis of score distribution to the left (right/positive skew; >0) or to the right (left/negative skew; <0)

Shannon entropy: Describes information content of score character using bits/character as unit. Higher values indicate more information per number

Total redundancy: Describes the number of redundant scores in a model.

Table 5 Scaling relationships of anatomical measurements with body mass according to $y = aBM^b$, with an additional factor c (if significant in log-transformed regression)

y	a [95% CI]	p	b [95% CI]	p	R²	c [95% CI]	p
Circumference front	10.9 [7.9-15.1]	< 0.001	0.29 [0.25-0.33]	< 0.001	0.72		
Circumference hind	14.8 [11.5-19.2]	< 0.001	0.25 [0.22-0.28]	< 0.001	0.69		
Length front	4.3 [3.1-6.0]	< 0.001	0.27 [0.23-0.31]	< 0.001	0.60		
Length front	4.1 [2.9-5.7]	< 0.001	0.27 [0.23-0.32]	< 0.001	0.63	0.002 [0.001-0.003] (Care Score)	0.009
Length hind	5.8 [4.4-7.7]	< 0.001	0.24 [0.21-0.28]	< 0.001	0.64		
Width front	3.5 [2.6-4.8]	< 0.001	0.29 [0.25-0.33]	< 0.001	0.65		
Width front	3.4 [2.5-4.7]	< 0.001	0.29 [0.25-0.33]	< 0.001	0.67	0.001 [0-0.003] (Care Score)	0.049
Width front	3.4 [2.5-4.7]	< 0.001	0.29 [0.25-0.33]	< 0.001	0.66		
Width hind	3.1 [2.1-4.5]	< 0.001	0.27 [0.22-0.31]	< 0.001	0.55		
Width hind	2.8 [1.9-4.0]	< 0.001	0.28 [0.23-0.32]	< 0.001	0.58	0.004 [0.001-0.006] (Pad Score)	0.010

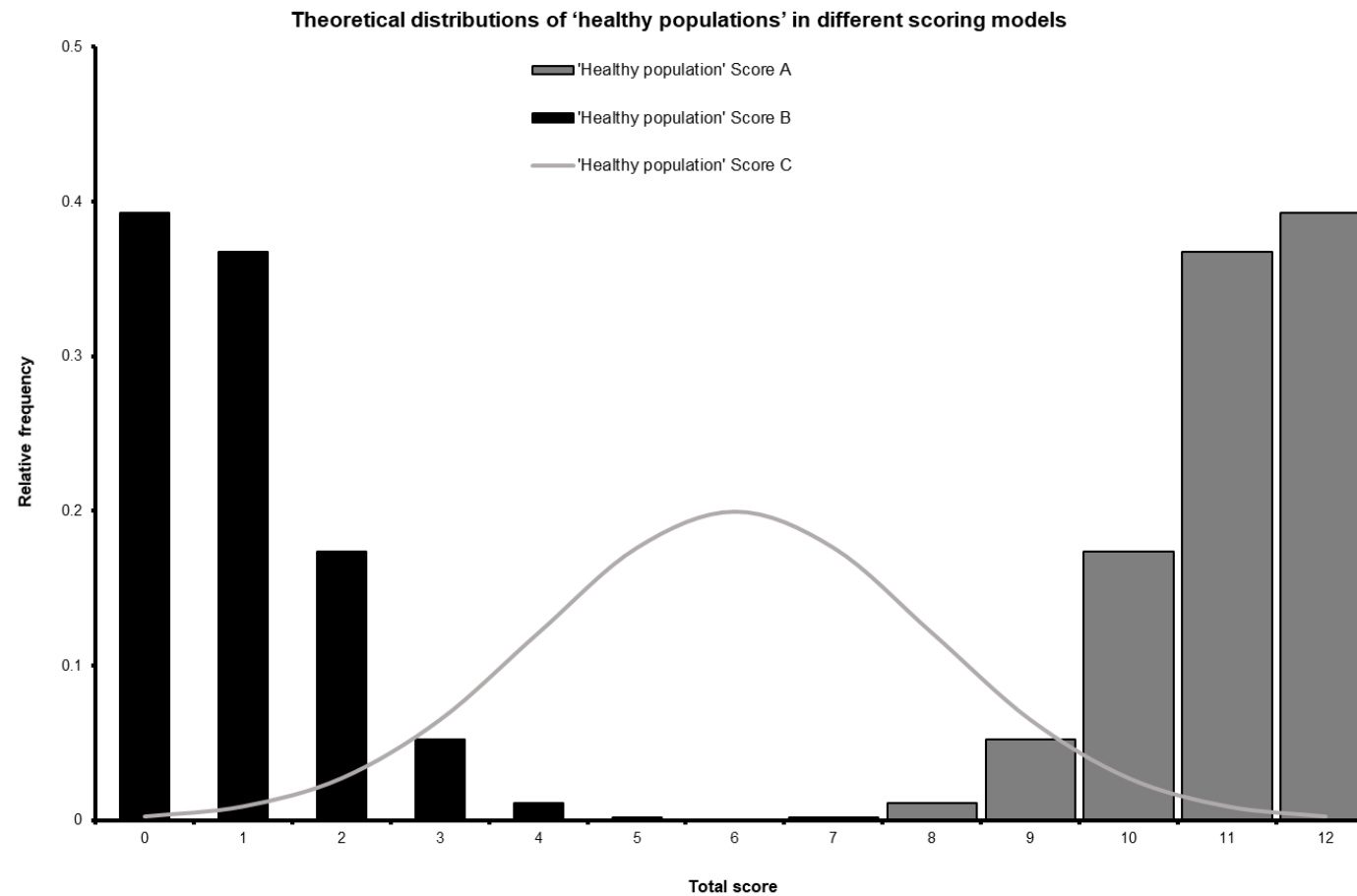


Figure 1 Theoretical distributions of 'healthy populations' in different scoring models

Score A represents a score where a healthy individual reaches the maximum number of points and deductions are made for health problems. Score B represents a score where a healthy individual has a status of 'zero' and health problems accumulate in the score. Score C represents a score where the optimum is in the middle of the range, with both lower and higher scores indicating non-optimal health conditions.

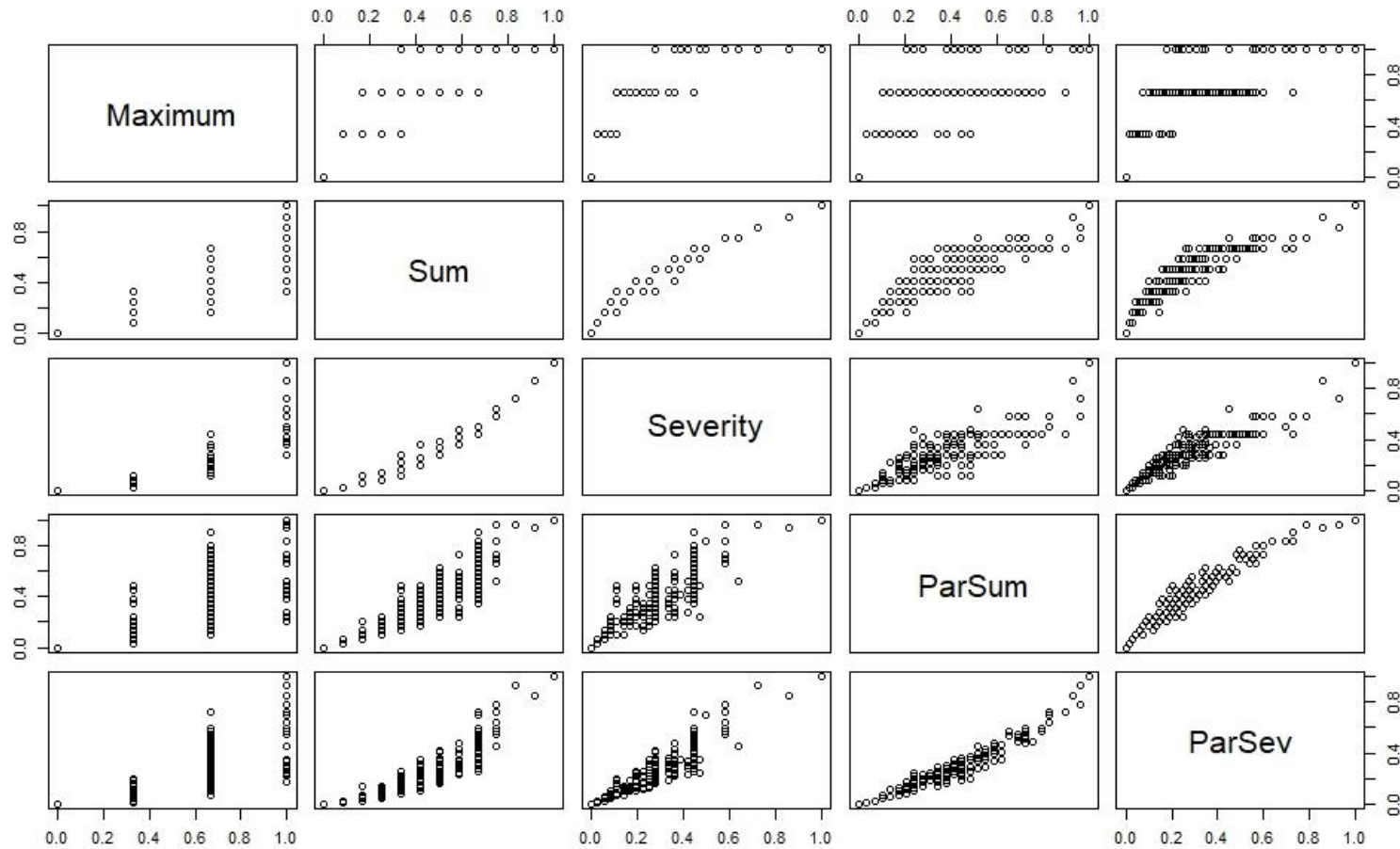


Figure 2 Correlation matrix of all scores (normalised to a scale of 0-1) in elephant feet used in the present study

Maximum: Maximum Score that scores an individual according to its worst occurring pathology (0-3); Sum: Sum Score that adds up the four feet score which are in turn scored according to their worst pathology (0-12); Severity: Severity Score that squares the foot values before adding them to weight pathologies (0-36); ParSum: Particularised Sum Score that adds up values from all nails and pads (0-66); ParSev: Particularised Severity Score that squares all nail and pad values before adding them up to weight all pathologies (0-198). Note that individual scores given by a less complex model (e.g. Maximum and Sum) correspond to a larger number of scores in more differentiated models (e.g. ParSum and ParSev).

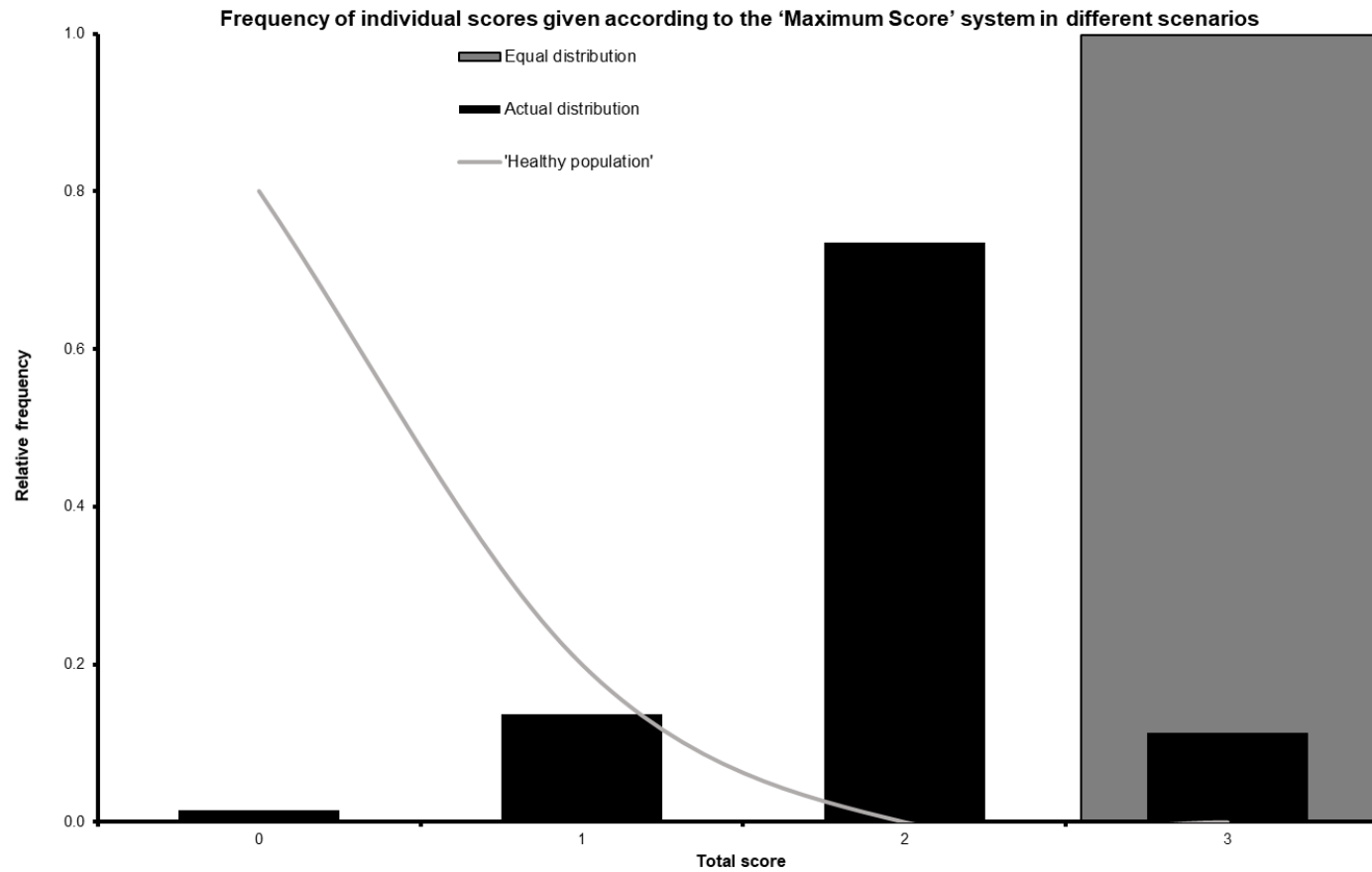


Figure 3 Frequency of individual elephant foot health according to the 'Maximum Score' system in different scenarios

Equal distribution assumes that all possible combinations of elephant foot pathologies occur with equal frequency. Actual distribution depicts the results in our sample population. 'Healthy population' describes a hypothetical optimally healthy population. Note the compelling discrepancy between the actual and the hypothetically healthy population, and that an equal occurrence of all possible combinations leads to the impression of a completely unhealthy population.

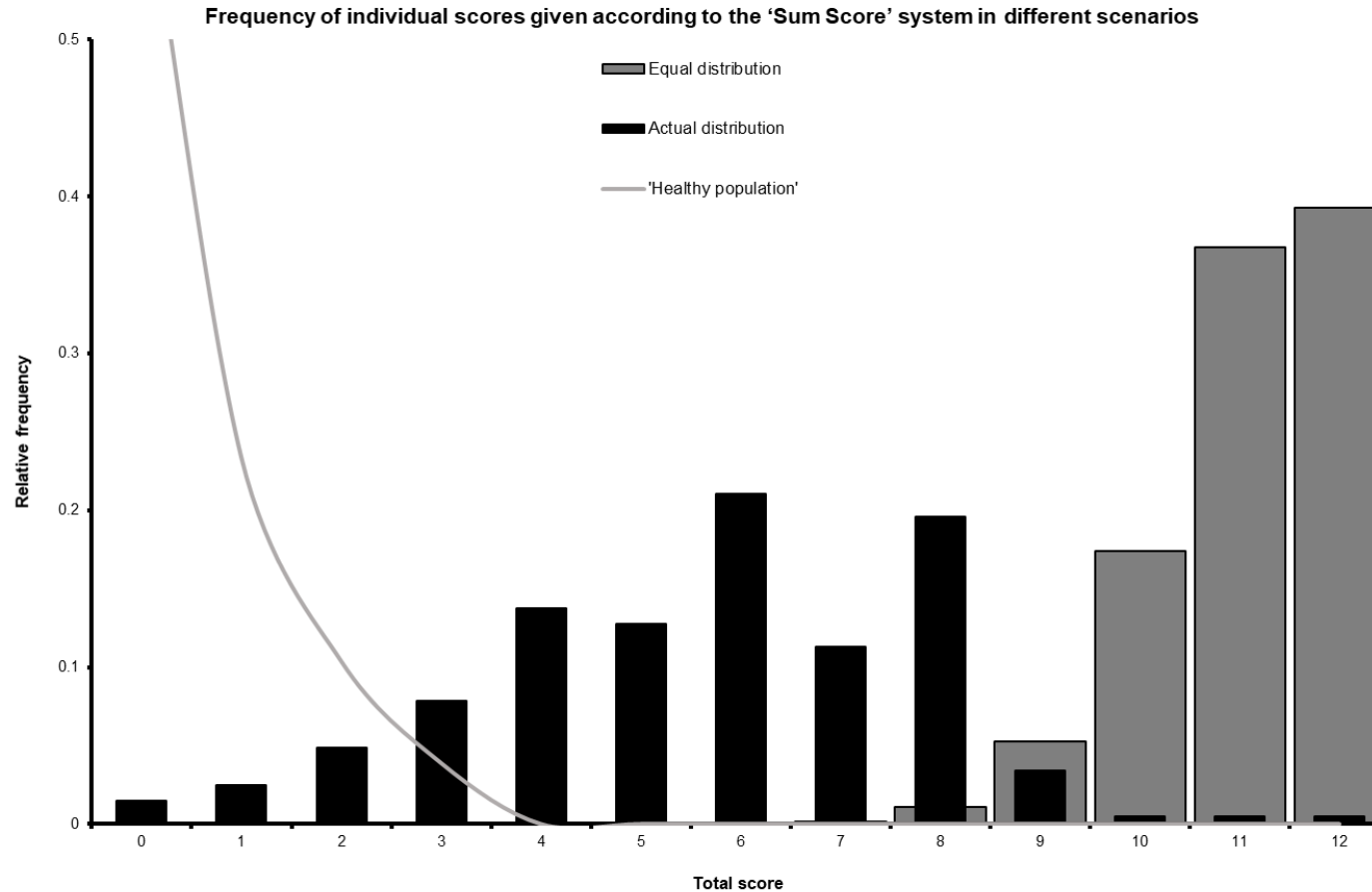


Figure 4 Frequency of individual elephant foot health according to the 'Sum Score' system in different scenarios

Equal distribution assumes that all possible combinations of elephant foot pathologies occur with equal frequency. Actual distribution depicts the results in our sample population. 'Healthy population' describes a hypothetical optimally healthy population. Note the stark discrepancy between the actual and the hypothetically healthy population, and that an equal occurrence of all possible combinations leads to the impression of a completely unhealthy population.

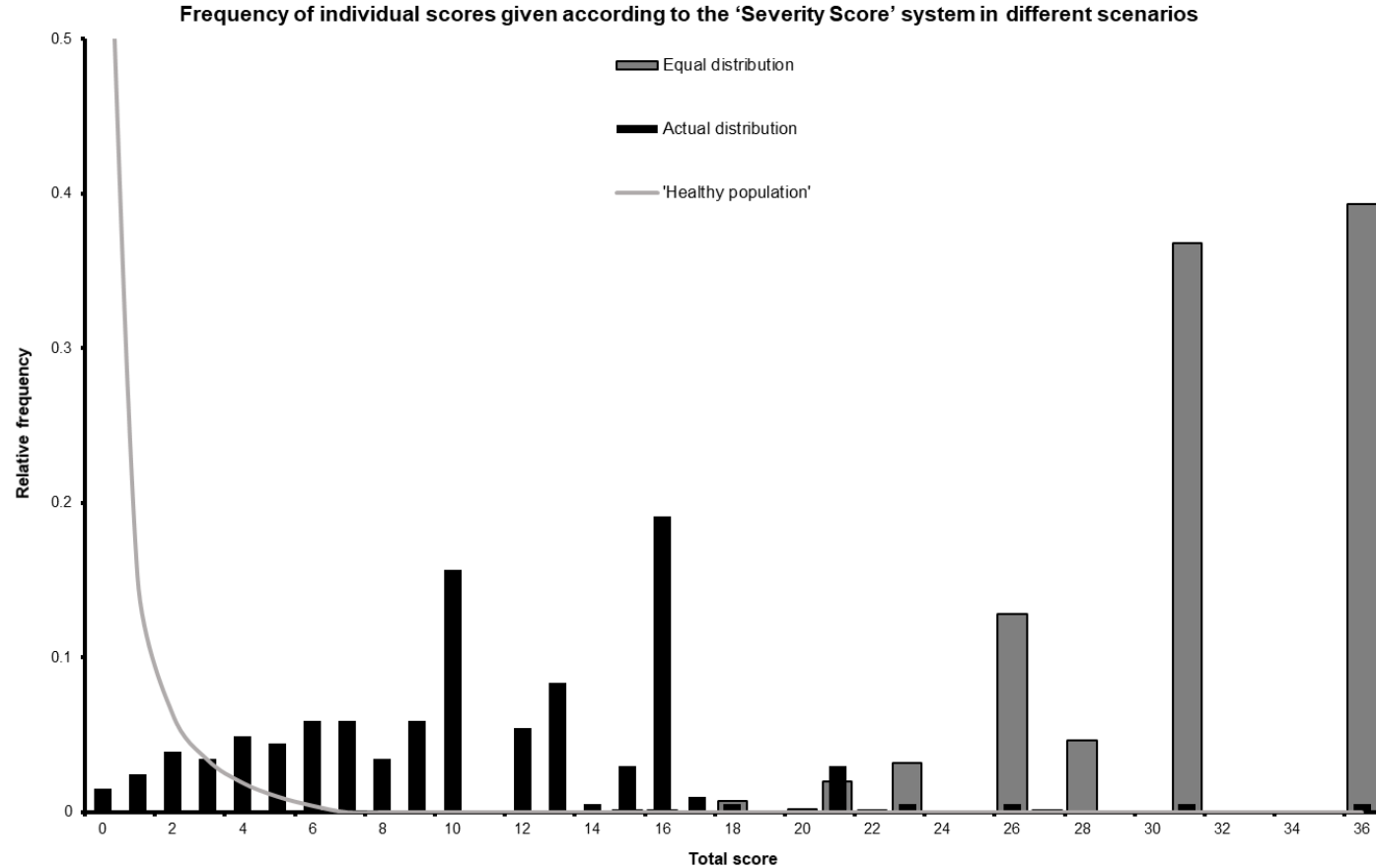


Figure 5 Frequency of individual elephant foot health according to the 'Severity Score' system in different scenarios

Equal distribution assumes that all possible combinations of elephant foot pathologies occur with equal frequency. Actual distribution depicts the results in our sample population. 'Healthy population' describes a hypothetical optimally healthy population. Note the discrepancy between the actual and the hypothetically healthy population, and that an equal occurrence of all possible combinations leads to the impression of a very unhealthy population.

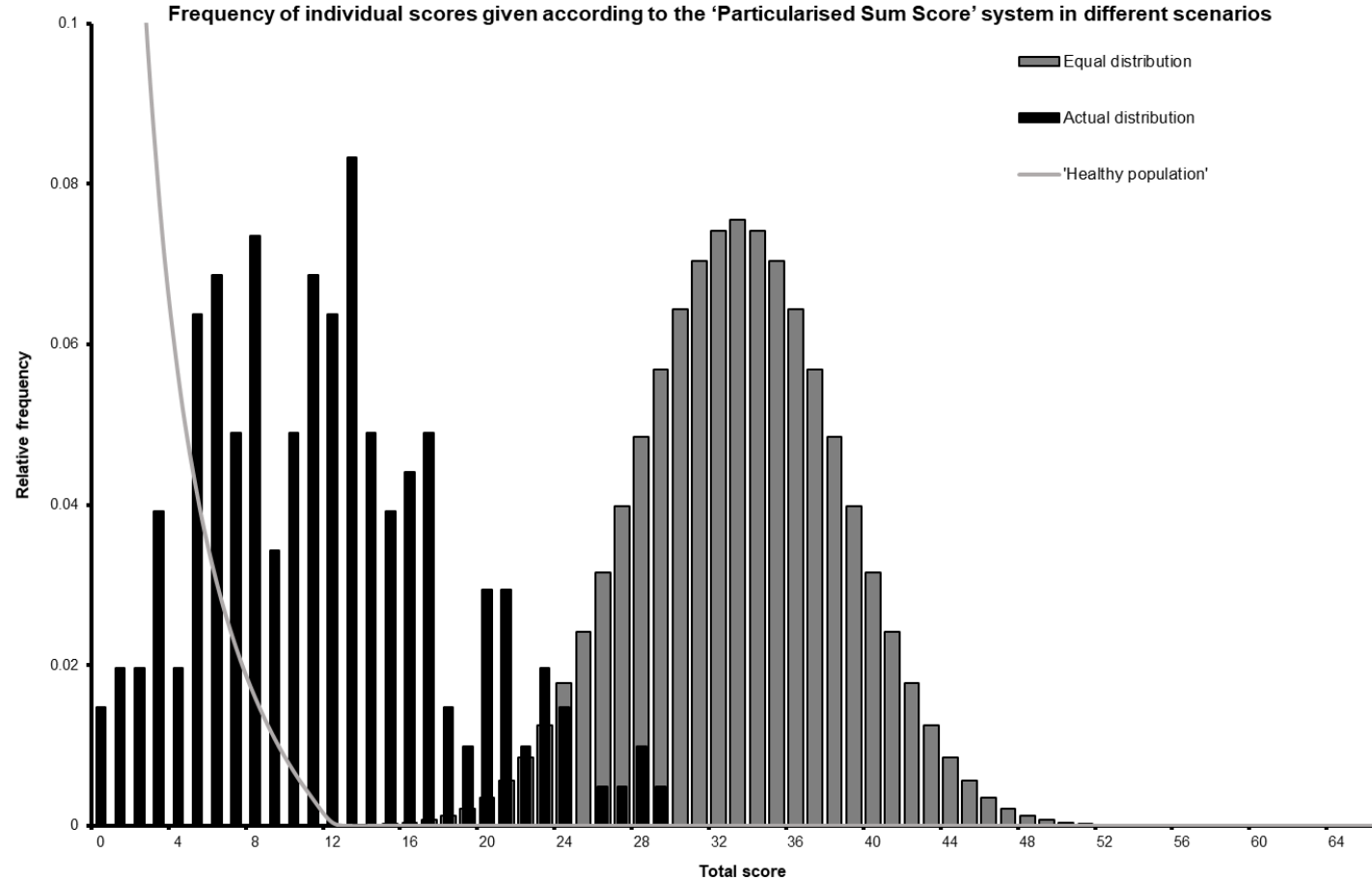


Figure 6 Frequency of individual elephant foot health according to the 'Particularised Sum Score' system in different scenarios. Equal distribution assumes that all possible combinations of elephant foot pathologies occur with equal frequency. Actual distribution depicts the results in our sample population. 'Healthy population' describes a hypothetical optimally healthy population. Note the actual distribution's shift towards the hypothetically healthy population compared to less complex models, and that an equal occurrence of all possible combinations leads to a normal distribution of score values.

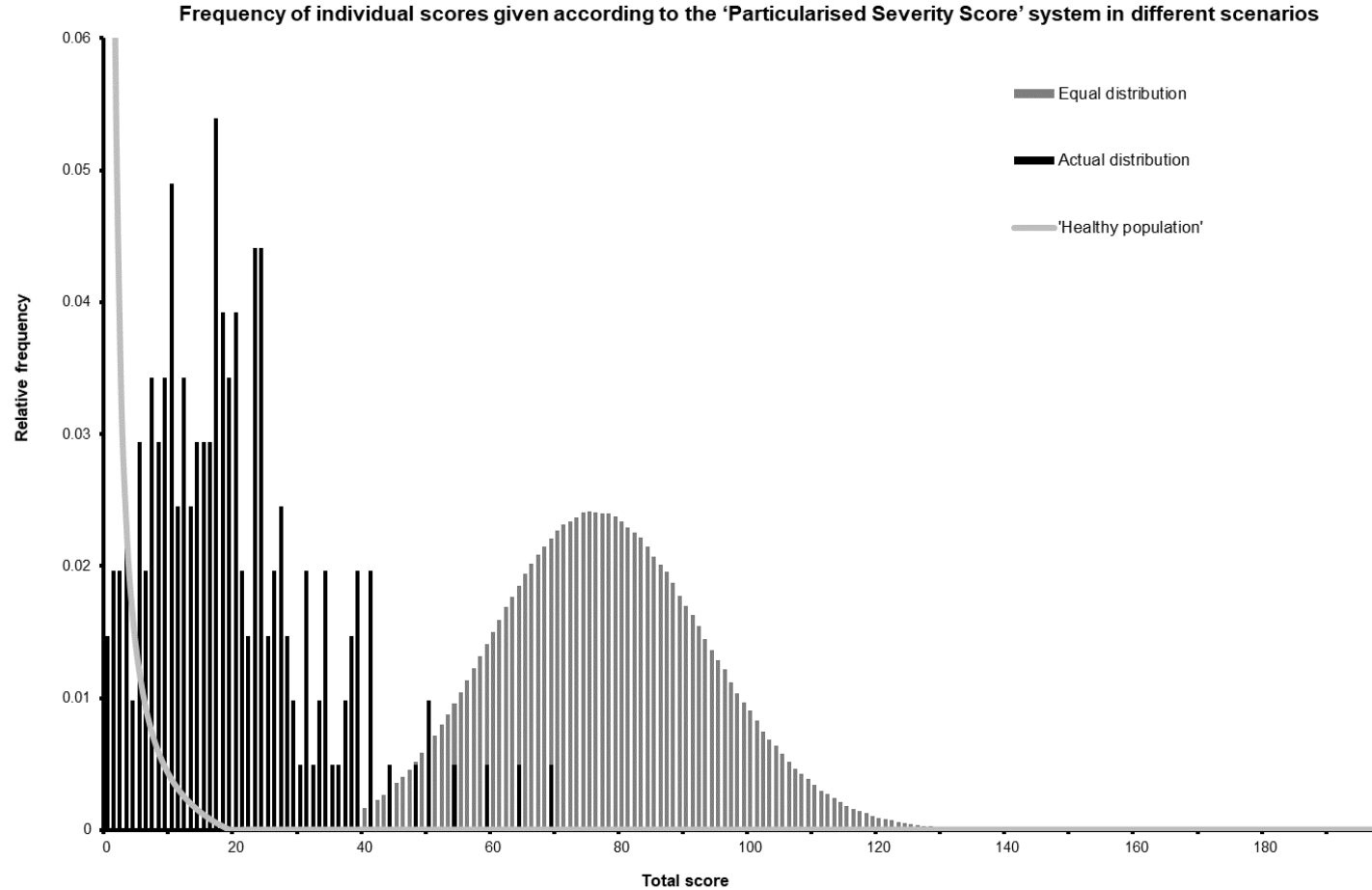


Figure 7 Frequency of individual elephant foot health according to the 'Particularised Severity Score' system in different scenarios
 Equal distribution assumes that all possible combinations of elephant foot pathologies occur with equal frequency. Actual distribution depicts the results in our sample population. 'Healthy population' describes a hypothetical optimally healthy population. Note the actual distribution's further shift towards the hypothetically healthy population compared to less complex models, and that an equal occurrence of all possible combinations leads to a normal distribution of score values.

**Influencing factors on the foot health of captive Asian elephants
(*Elephas maximus*) in European zoos**

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RESEARCH ARTICLE

Influencing factors on the foot health of captive Asian elephants (*Elephas maximus*) in European zoos

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Pathological lesions of feet occur frequently in captive elephant populations. To improve foot health, it is important to identify risk factors associated with such pathologies. Several previous studies have analyzed potentially influencing factors but were limited, for example, by small sample sizes. This study analyzed relations between 87 independent variables and the foot health score of 204 Asian elephants (*Elephas maximus*) in European zoos using bivariate correlation, multivariable regression models and principal component analysis (PCA). Correlation and regression tests revealed significant results for 30 different variables, mainly with small effect sizes. Only three variables were significant in more than one test: sex, time spent indoors, and time spent on hard ground, with lower scores (i.e. less or less severe pathological lesions) in females, and when less time is spent indoors or on hard ground. Due to small effect sizes and differing results of the statistical tests, it is difficult to determine which risk factors are most important. Instead, a holistic consideration appears more appropriate. A biplot of the PCA shows that factors representing more advanced husbandry conditions (e.g. large areas, high proportions of sand flooring) were associated with each other and with decreased foot scores, whereas indicators of more limited conditions (e.g. high proportions of hard ground, much time spent indoors) were also associated with each other but increased the foot score. In conclusion, instead of resulting from just one or two factors, reduced foot health might be an indicator of a generally poorer husbandry system.

KEYWORDS

elephant, flooring, health, husbandry, management

1 | INTRODUCTION

As the largest terrestrial mammal with sophisticated cognitive abilities and a complex social structure, elephants are a very popular species kept in many of the larger zoos worldwide. By holding elephants in captivity, we take responsibility for their welfare and for

providing conditions that prevent suffering due to health issues and pain. There is intensive research on infectious diseases and the investigation of reproductive aspects already yielded major successes, for example in the establishment of artificial insemination techniques (Hildebrandt et al. 2006, Long, Latimer and Hayward 2016, Thongtip et al.

2009). Another very important topic of elephant medicine is foot health, since foot problems have a high incidence in different captive populations (80.4% in the UK (Harris, Sherwin and Harris 2008), 98.5% in Europe (Wendler et al. 2019), 67.4% in North America (Miller, Hogan and Meehan 2016)) and can represent a reason for euthanasia (Mikota, Sargent and Ranglack 1994). Common alterations are overgrown nails, pads or cuticles, nail or pad abscesses, fluid pockets in the cuticles and nail cracks (Lehnhardt 2006, Roocroft and Oosterhuis 2001, Rutkowski, Marion and Hopper 2001, Wendler et al. 2019).

To reduce the risk of such problems, an epidemiological approach is utilized to detect potential influencing factors, collect inputs and outcomes at various collections and build multivariable models to assess relationships (Meehan, Mench, Carlstead and Hogan 2016). Several studies have previously investigated factors that could affect elephants' foot health (Table 1). Few associations were found, with some of them differing between studies. Most of the investigations were based on a data collection performed by local zoo staff (Haspeslagh et al. 2013, Lewis, Shepherdson, Owens and Keele 2010, Miller et al. 2016) or the analyzed sample sizes was below 100 animals (Harris et al. 2008, Haspeslagh et al. 2013, Lucas and Stanyon 2017, Miller et al. 2016). A typical problem when analyzing influencing factors is to distinguish between factors that might indicate a causal relationship, and proxy indicators or confounding factors. In particular, common sense would predict that a range of details considered typical for more advanced husbandry should covary. For example, a facility with large exhibits also has a higher amount of natural flooring, a larger group size and a lower mean group age. If in this case a significant correlation is found between group size and foot health, does it really mean that a higher group size is beneficial for the foot health or is it just representative for generally good husbandry conditions?

The aim of this study was the investigation of a broad variety of potentially influencing factors on the foot health of Asian elephants (*Elephas maximus*) by the application of different statistical analyses. The investigation

was based on a comprehensive sample size, including the European Endangered Species Programme (EEP) population, and a standardized data collection ensured by personal visits to the institutions.

2 | MATERIALS AND METHODS

2.1 | Ethics statement

The project was authorized by the management of each participating institution. Additionally, it was approved by the Elephant Taxon Advisory Group (TAG) of the European Association of Zoos and Aquaria (EAZA) and the British and Irish Association of Zoos and Aquariums (BIAZA). The study was non-invasive.

2.2 | Data collection

Between August 2016 and July 2017, 69 zoos were visited by two veterinarians and data of 243 elephants (≥ 5 years old) was collected. To evaluate each elephant's foot health, pictures of every nail in cranial and solar perspective as well as of the pad (only in solar perspective) were taken and analyzed concerning occurring pathological lesions (Wendler et al. 2019). In order to facilitate an associative epidemiological investigation, these lesions were given a score between 0 and 3 according to their severity (Ertl et al. 2019). To determine the foot health status that included all findings of one elephant, a new scoring system was developed, considering the number of altered locations as well as the severity of the lesions (Ertl et al. 2019). This total score was defined as "Particularised Severity Score" (ParSev Score). Additionally, data concerning potentially influencing factors was collected by interviewing keepers, curators or veterinarians regarding herd and individual parameters (Appendix 1 and 2). Underlying questions for these interviews were developed beforehand in consultation with zoo veterinarians and elephant care takers of different zoos, while also taking literature on elephant management into account (Csuti, Sargent and Bechert 2001, Lehnhardt 2006).

TABLE 1 Previous studies on influencing factors on the elephant's foot health and their results

Study	Method	Sample size	Influencing factor	Effect on foot health
Harris et al. (2008)	3 visits in 13 UK zoos	41 Asian and 36 African elephants	Age	Negative effect on foot health
			Species	No significant effect
			Total indoor space	No significant effect
			Total outdoor space	No significant effect
			Indoor space/individual	No significant effect
			Locomotion score	No significant effect
			Time spent stereotyping	No significant effect
			Mean FCM concentration (fecal cortisol metabolite – stress level)	No significant effect
			Body condition score	No significant effect
			Contact type	Positive effect of “no contact” on foot health (but could not be assessed equally)
Lewis et al. (2010)	Survey in 78 North American facilities	137 Asian and 151 African elephants	Herd age	Negative effect on foot health (1 year increase in herd age → 15% increase in likelihood of pathological lesions)
			Species	African herds showed slightly better foot health than Asian herd, but this is due to the herd age
			FTE/elephant (full time equivalents – keepers)	No significant effect
			Management system	No significant effect
			Exercise	Positive effect on foot health (10 min more exercise per day → 37% decrease in likelihood of pathological lesions)
			Indoor size	No significant effect
			Indoor concrete	No significant effect
			Tethering	No significant effect
Sarma et al. (2012)	Survey and examination in eastern India	312 Asian elephants	Age	Negative influence on foot health
			Sex	Females better foot health than males
			Limbs	Front limbs better than hind limbs
			Keeping conditions	Negative effect of muddy conditions on foot health
			Work assignment	Negative effect of logging on foot health
Haspeslagh et al. (2013)	Questionnaire in 32 European zoos	87 Asian elephants	Floor type	Negative effect of concrete and sand on foot health No significant effect of rocks, grass, tiles, asphalt, dirt, rubber and straw
			Stereotypic behavior	Negative effect on foot health
			Age	No significant effect

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Miller et al. (2016)	North American zoos, Examination through local zoo vet	32 African and 32 Asian elephants included in statistical analysis	Space Experience, Night	Negative effect on foot health
			Percent Time In/Out Choice, Day	Negative effect on foot health
			Time on Hard Substrate	Negative effect on foot health
			Sex	No significant effect
			Species	No significant effect
			Origin	No significant effect
			Environment contact	No significant effect
			Mean daily walking distance	No significant effect
			Body condition score	No significant effect
Lucas and Stanyon (2017)	Case report of a UK zoo	2 African elephants	Indoor floor type changed from concrete to sand, indoor area increased, feeding and management improved	Positive effect on foot health

2.3 | Statistical analysis of influencing factors using bivariate correlation

Statistical analyses were conducted using R software Version 3.4.4. Based on the data from studbook and interviews, 87 potentially influencing factors were defined as independent variables (Appendix 3). They covered information regarding individual characteristics, foot care, management, enclosure, diet and climate. Variables of ordinal or continuous character were related to the ParSev Score using Spearman's rank correlation. Variables of dichotomous character were analyzed using point-biserial correlation coefficient. The effect size was evaluated as small ($0.1 \leq |r| < 0.3$), medium ($0.3 \leq |r| < 0.5$) or large ($|r| \geq 0.5$) according to Cohen (1988, 1992).

2.4 | Statistical analysis of influencing factors using multivariable linear regression models

To further analyze the impact of independent variables on the foot health, two multivariable linear mixed regression models were used with step-wise regression. The first model considered single nail values (range 0 – 3) as dependent variable, whereas the second one used the ParSev Score in a gamma-distributed model. The number of independent variables needed to be reduced to fit the models. Reasons for exclusion of a variable were small variability (e.g. particular chronic diseases and stereotypies occurred only in a very small number of elephants), few data points (e.g. diet components, where exact data on quantity and body mass could only be provided by few institutions) and a presumed low importance (e.g. precipitation and temperature with far from significant results in the single correlation). To avoid calculation errors based on zero values, one was added to all scores. Since some of the included variables were zoo-specific (e.g. enclosure sizes, ground types) and therefore with equal values for the majority of elephants within the same institution, those variables were subsumed as random effect 'zoo' and their particular impact could not be analyzed in this model (Appendix 3).

2.5 | Statistical analysis of influencing factors using a multivariable linear regression model with mean values for each zoo

To investigate variables that were previously subsumed as random effect 'zoo' concerning their influence on the ParSev Score, mean values for each institution were calculated and put into context with the mean ParSev Score for the institution. Again, a gamma-distributed linear regression model was used, including the same variables as in the first regression model except for individual variables (e.g. sire, origin, dominance) and including diet components and time on hard ground instead.

2.6 | Statistical analysis using principal component analysis

A principle component analysis was used including 25 variables and the ParSev Score to further investigate relations between these factors. Since some variables (e.g. areas) showed a highly-skewed distribution, the logarithm was used to transform the data. If these variables included zero values, a value of 1 was added before log-transformation. Calculated component scores and loadings were visualized using a biplot.

2.7 | Interpretation of associations

The interpretive approach to significant associations varies depending on the expected relation to the variable of interest, which is the elephants' foot health in the present study. Formally, it cannot be decided, based on the data alone, whether an association indicates causality (as in: hard flooring causes foot problems, which explains a positive association between floor hardness and foot problems), a putative reaction (as in: animals with compromised foot health are kept on soft flooring to address the health issue, which explains a negative association between floor hardness and foot problems), or whether it is just a coincidental finding because one of the variables is associated to a third variable like a 'proxy' (as in: institutions with harder floors keep older animals, and because older animals

have more foot problems for other reasons, this results in a positive association between floor hardness and foot problems). Evidently, the absence of an association (in our example, between floor hardness and foot health) might then be caused by a mix of facilities where causation is active, and facilities where reactions have been instigated. This leads to the methodological dilemma that a priori, any result can be put into a narrative that corroborates a preconception (in our example, the preconception that hard floors cause foot problems). We are aware of this fundamental problem of associative, epidemiological surveys, and caution readers against considering associations as more than circumstantial evidence. Using different multivariate statistical approaches does not prevent this fundamental issue, because the dilemma whether a significant influence factor is causative or reactive, or a nonsignificant factor is a mix of both, remains. Therefore, results as those of the present study should inform readers about putative measures that can be taken to ameliorate a certain situation, the validity of which can only be assessed by experiments or case series.

3 | RESULTS

3.1 | Bivariate correlation

The correlation to the ParSev Score was tested for 19 dichotomous variables using point-biserial correlation coefficient and for 64 variables using Spearman rank correlation. A significant correlation was found for 25 of these variables (Table 2). The highest correlation coefficient r_s was found for the amount of browse provided per elephant and day ($r_s = -0.60$ [strong effect], $p < 0.001$), followed by the amount of time spent on hard ground ($r_s = 0.39$ [medium effect], $p = 0.001$), the amount of sand in the enclosure ($r_s = -0.31$ [medium effect], $p < 0.001$), and the size of the indoor area ($r_s = -0.30$ [medium effect], $p < 0.001$). For all other variables, the correlation coefficient was less than 0.3 [small effect].

3.2 | Multivariable linear regression model

The generalized linear mixed model, analyzing the relation of variables to single nail values, detected sex, two sires, and two countries as significant predictors. In particular, significantly lower (i.e., healthier) nail values were found for females in comparison to males ($p = 0.001$), for elephants that were fathered by Male A ($p = 0.001$) or Male B ($p = 0.033$), and elephants kept in Country 1 ($p = 0.009$) or Country 2 ($p = 0.010$).

The gamma-distributed generalized linear mixed model, which considered the ParSev Score as dependent variable, revealed sex ($p = 0.001$), chronic diseases ($p = 0.004$) and relatives ($p = 0.046$) as significant. Again, females were found to have a lower score than males. Elephants suffering from a chronic disease showed significantly higher foot scores, whereas animals that were kept together with an immediate relative had lower scores.

3.3 | Multivariable linear regression model with mean values

Using mean values for each institution in a linear regression model, significant correlations to mean ParSev Scores were found for the amount of time spent on hard ground ($p = 0.001$, $n = 28$), mean time spent indoors ($p = 0.002$, $n = 60$) and body mass ($p = 0.022$, $n = 32$) when analyzed separately. Higher ParSev Scores were associated with increasing amount of time on hard ground and time spent indoors as well as with decreasing body mass. When these three variables were merged in one model, none of them showed any significant correlation anymore ($n = 12$).

3.4 | Principal component analysis

The first principle component (PC1) explained 22.6% and the second component (PC2) additional 10.2% of the variance. Hence, the biplot of PC1 and PC2 described nearly a third of the variance of this data set (Figure 1). Points in the plot signify individual elephants, whereas eigenvectors show relations between the variables. Eigenvectors pointing in similar

TABLE 2 Variables with significant bivariate correlation using Spearman's rho r_s or point-biserial correlation coefficient r_{pbi} for dichotomous variables to the ParSev Score ($p < 0.05$)

Variable	n	r_s / r_{pbi}	p-value	Effect size
I. Individual characteristics				
Chronic skin disease [present, not present]	204	0.16†	0.021	Small
Sex [male, female]	204	-0.15†	0.031	Small
Stereotypic nodding [hours/day]	204	0.15	0.035	Small
II. Foot care				
Care score [0-62]	191	0.20	0.004	Small
Cooperativity [1-5]	204	-0.19	0.006	Small
Pad score [4-16]	204	0.16	0.019	Small
Washing [daily, every 2 nd or 3 rd day, weekly, less frequent, never]	204	-0.16	0.025	Small
Wet feet [daily, every 2 nd or 3 rd day, weekly, less frequent, never]	204	-0.15	0.030	Small
III. Management				
Current time outdoors [hours/day]	204	-0.14	0.041	Small
Exercise [hours/week]	204	0.16	0.024	Small
Free choice availability [yes/no]	204	-0.16†	0.022	Small
Group size [/]	204	-0.16	0.020	Small
Time free choice [hours/day]	204	-0.22	0.001	Small
Time indoors [hours/day]	204	0.25	< 0.001	Small
IV. Enclosure				
Area per animal [m ²]	192	-0.15	0.038	Small
Ground sand [%]	188	-0.31	< 0.001	Medium
Ground grass [%]	188	0.15	0.041	Small
Indoor area [m ²]	192	-0.30	< 0.001	Medium
Mean area [m ²]	192	-0.26	< 0.001	Small
Time hard ground [%]	71	0.39	0.001	Medium
V. Diet				
Biotin [mg/animal]	192	0.19	0.008	Small
Browse [g/kg ^{0.85}]	37	-0.60	< 0.001	Large
Grass [g/kg ^{0.85}]	114	-0.22	0.016	Small
Silage [g/kg ^{0.85}]	196	-0.24	0.001	Small
Vegetables [g/kg ^{0.85}]	88	-0.24	0.027	Small

† for dichotomous variables instead of Spearman's rho r_s the point-biserial correlation coefficient r_{pbi} was calculated; effect size evaluated according to Cohen: small: $0.1 \leq |r| < 0.3$, medium: $0.3 \leq |r| < 0.5$, large: $|r| \geq 0.5$

directions are positively correlated in the first two principle components, whereas eigenvectors pointing in opposite directions are negatively correlated. Therefore, a higher ParSev Score (i.e. more or more severe pathological lesions) is for example associated with more time indoors, a higher amount of hard ground in the enclosure, less area per animal, less time with free access to in- and outdoor enclosure and less cooperativity during foot care. The longer the eigenvector the higher is the contribution of the corresponding variable. For example, area per animal has a higher contribution than

cooperativity during foot care in the first two principle components. The eigenvector of the ParSev Score lies in the third quadrant of the coordinate system, together with time spent indoors, amount of hard ground in the enclosure and number of years of experience of the keepers, to name the three strongest eigenvectors. Pointing in the opposite, first quadrant, predominant eigenvectors are mean enclosure area, the time the elephants can choose whether to stay in- or outdoors, area per animal as well as the amount of sand in the enclosure. The second quadrant shows variables which were, with regard to the

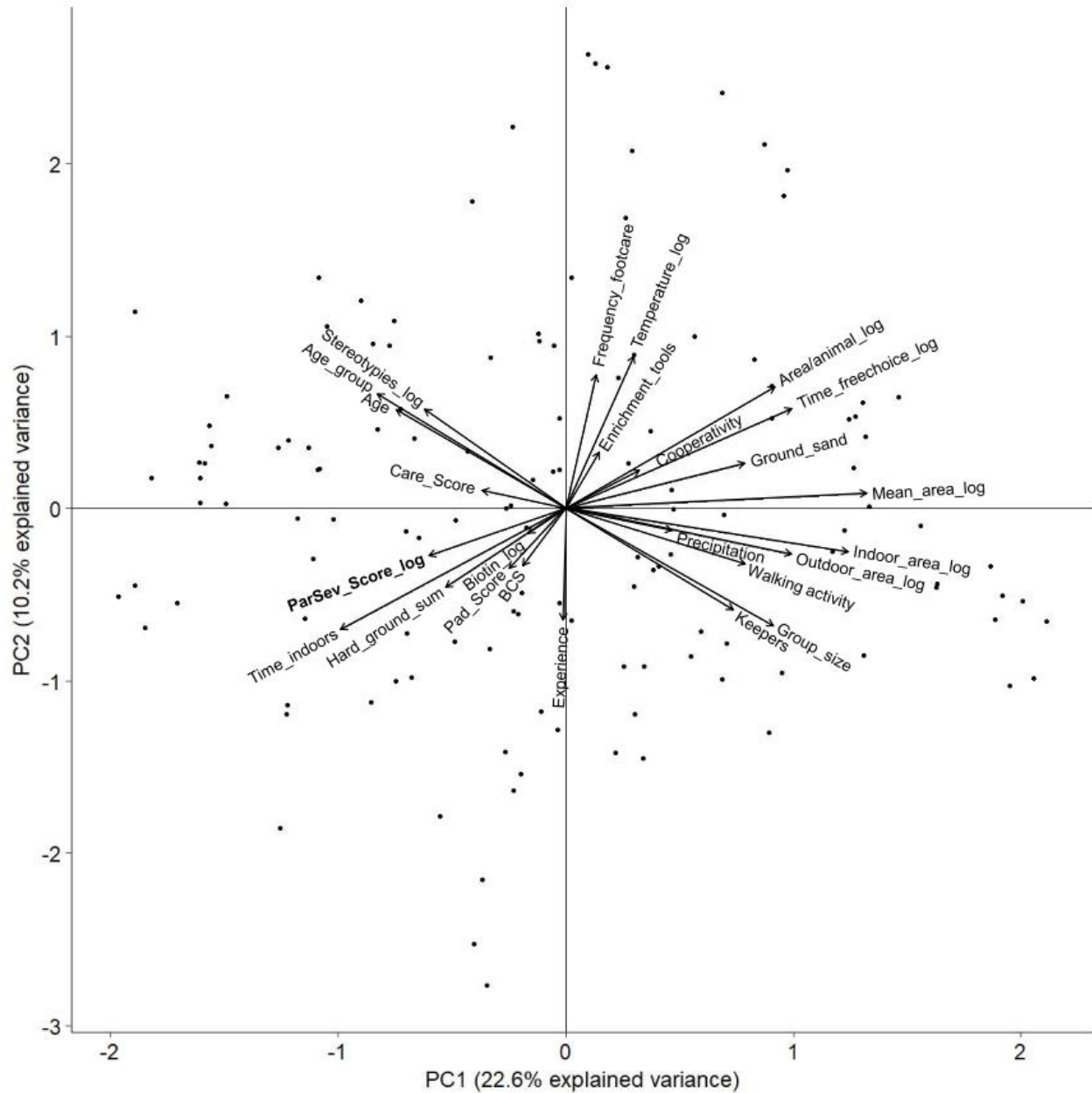


FIGURE 1 Biplot of the principle component analysis of data concerning foot health and related husbandry factors of captive Asian elephants (*Elephas maximus*) showing principle component 1 and principle component 2

ParSev Score, positively related in the first, but negatively related in the second principal component. Most important eigenvectors here are mean age of the group, age and amount of time spent stereotyping per day. Opposite, in the fourth quadrant, we can find size of the indoor and outdoor area as well as mean group size.

4 | DISCUSSION

Based on the data of a comprehensive proportion of the EEP population of Asian elephants (82.9% of all elephants aged 5 years or older (Wendler et al. 2019)) and using a foot scoring system suitable for epidemiological approaches (Ertl et al. 2019), necessary requirements for the analysis of influencing

factors on the foot health were met. To identify risk factors for pathological lesions of feet, various independent variables covering distinct topics were investigated. But dealing with a high number of independent variables is difficult and often requires the use of different statistical analyses. Simple statistics, such as single variable correlation used in this paper, do not consider multicollinearity, which means that relationships among the independent variables are not taken into account. Therefore, the validity of these tests is limited. Multivariable linear regression models help identifying individual risk factors but can also be influenced by multicollinearity. In contrast to that, the principle component analysis deals with the problem of multicollinearity but does not identify individual predictor variables with significant influence on the dependent variable (Dohoo, Ducrot, Fourichon, Donald and Hurnik 1997). To compensate for the shortcomings of each statistical test, all three methods were applied in the present study. However, for most variables, a significant correlation was only found in one of the statistical tests and effect sizes were often small. Therefore, it is difficult to draw an explicit conclusion concerning the risk factors for pathological lesions of feet from these results. Nevertheless, we discuss observed significant correlations as well as the general context.

4.1 | Individual characteristics

Sex was the only variable with a significant correlation to foot health in three different statistical tests. The bivariate correlation revealed a small but significant effect, and there was also significance in the regression models with single nail values and the ParSev Score. According to these statistics, females had less or less severe foot problems than males. No significant effect of sex was found by Miller et al. (2016), but there were only 7 males included in the analysis, whereas 48 male elephants were analyzed in our study. Within captive elephants in India, Sarma, Thomas, Gogoi, Sarma and Sarma (2012) also found a higher incidence of foot problems in males, which were explained by chaining, and reduced hygiene and foot care, during the months of musth. In the included European

zoos, no male elephant was chained during musth, but several keepers reported that during this period of higher testosterone levels, foot care is not as feasible as usually. Since most males were kept either separately from females or in “bachelor groups”, different husbandry conditions could also be reason for the increased ParSev Scores. But using Wilcoxon rank sum test, we did not find a significant difference for the key elements time spent indoors, mean area and amount of sand as substrate between the sexes. Hence, males might require different husbandry conditions than females to ensure healthy feet. However, the difference in the mean ParSev Scores (females: 18.3, males: 21.4; total score range: 0 – 69) was small, meaning that for example a male had three minor nail cracks more than a female.

West (2001) reported increasing age as a risk factor for foot problems, which was confirmed by the study from Harris et al. (2008). In contrast, no statistical test in our study revealed a significant correlation between age and foot health, which corresponds to the results from Haspeslagh et al. (2013). Although increasing age is often mentioned by keepers and veterinarians as risk factor for foot problems, the results of our study cannot confirm this, and age seems, if at all, only to be a proxy indicator for other influencing conditions.

A significant relationship was found when comparing mean body masses of animals in the same zoo with their mean ParSev Scores using a multivariable linear regression model. Higher mean body masses came along with less or less severe pathological lesions. Due to the nonparametric nature of the correlation, no statistically supported equation can be given, but the overall pattern indicated a decrease of the ParSev Score by 2.6 points for every 500 kg difference, which is a rather small effect. The significant correlation should be interpreted with caution, since all analyses on individual basis did not show any relationship, and for the analysis of mean values only 32 data points could be used. Moreover, this result contrasts with the common assumption that higher body masses lead to more foot problems due to higher peak pressures (Hughes and Southard 2001, Roocroft and

Oosterhuis 2001, Sadler 2001, West 2001). No association was found between the body condition score (data from Schiffmann et al. (2018)) and ParSev Score, which is in accordance with the results of Harris et al. (2008).

The regression model with single nail values revealed that descendants of Male A and Male B showed significantly healthier feet in comparison to other elephants (Figure 2), making a genetic component in the prevalence of foot problems conceivable. This has already been suggested by Seidon (2001) and Lehnhardt (2006), but has not been further analyzed so far and might present an objective for future research. For cattle, a low heritability of hoof health has already been proven (Malchiodi et al. 2017).

Within the regression model using the ParSev Score, elephants suffering from a chronic disease showed more or more severe foot problems. Again, there was only a small difference of four units in the mean ParSev Scores. Chronic diseases may decrease activity, which is suggested to correlate with more foot problems (Lewis et al. 2010, Roocroft and Oosterhuis 2001). Another explanation could be a compromised immune system due to the chronic suffering leading to a higher susceptibility towards foot lesions. There was also a significant result in the single

correlation of one particular chronic disease, namely skin disease. This result should be considered very carefully, because there were only 11 elephants suffering from a chronic skin disease. But since the evaluated structures of the feet are ontogenetically modified forms of the common integument (Bragulla, Budras, Mülling, Reese and König 2004), a co-occurrence with chronic skin diseases, or a relevance of a general susceptibility to skin diseases, is conceivable.

Stereotypic behavior has previously been associated with a higher risk for foot problems (Haspeslagh et al. 2013, Roocroft and Oosterhuis 2001). Nevertheless, there was no significant correlation between the estimated time the elephants displayed stereotypic behavior and foot health. But when analyzing particular stereotypic movement patterns (Haspeslagh et al. 2013) using bivariate correlation, a significant, but small effect was found between the amount of time spent in stereotypic nodding and the ParSev Score. Since only 8 of 243 elephants showed stereotypic nodding behavior, this result should also be considered with caution. To elucidate the impact of stereotypic behavior on an elephant's foot health, it might be essential to collect data regarding the specific movement pattern and duration of stereotypic behavior.

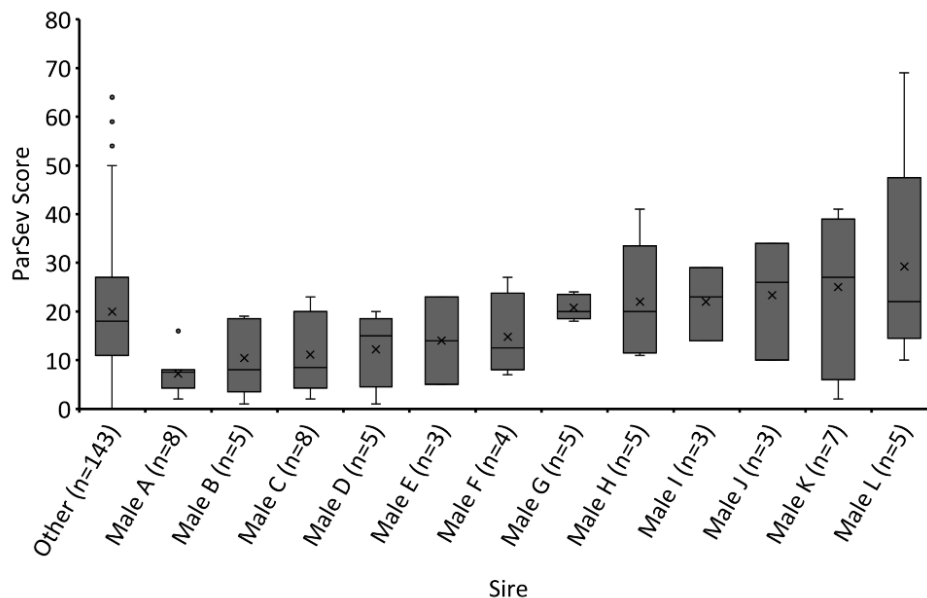


Figure 2 Relation between ParSev Score and sire in captive Asian elephants (*Elephas maximus*), only for sires with at least three descendants (n) in the study, all others referred as 'Other'

4.2 | Foot care

Foot care is the common procedure to prevent and treat foot problems in elephants under human care (Fowler 2001a, Roocroft and Oosterhuis 2001, Schwammer 2001, West 2001). From the variables concerning foot care, only small effects in the bivariate correlation could be found for cooperativity, frequency at which the elephants have wet feet, frequency of washing and the care and pad score. Elephants that were evaluated as being more cooperative during foot care showed less or less severe foot problems. This underlines the importance of a good training that allows the performance of an effective pedicure (Roocroft and Oosterhuis 2001).

Daily washing and scrubbing of the elephants' feet to remove dirt and monitor alterations are recommended by Roocroft and Oosterhuis (2001) and Schwammer (2001). But due to the results of our study, a higher frequency of washing or of wet feet through washing or pool usage led to a higher ParSev Score. Perhaps, washing of feet lost importance because of the improvement of husbandry. Nowadays, frequent wet feet seem to lead more to a weakening of the foot structures. Also Sarma et al. (2012) noticed that captive elephants in India had more foot problems when they lived under muddy conditions.

Care and pad scores were developed to evaluate care condition and roughness of foot pads (Ertl et al. 2019). Due to bivariate correlation, smaller ParSev Scores were found when elephants showed less care issues and smoother pads, which result from an adequate husbandry providing natural wear supported by foot care that balances probable deficiencies.

4.3 | Management

Time indoors was one of only three variables that reached significance in more than one statistical test, indicating that elephants kept less time indoors showed lower ParSev Scores (Figure 3a). Compared to North American zoos (Meehan, Hogan, Bonaparte-Saller and Mench 2016), elephants kept in European zoos spent nearly twice as much time indoors (28.9% vs. 53.4%), which could be a reason why a

significance was found in this study but not for the North American population (Miller et al. 2016).

In turn, the availability and a higher amount of time to choose whether to stay in- or outdoors, was associated with smaller ParSev Scores, using bivariate correlation. Although hypothesizing the same relationship, Miller et al. (2016) found an increased risk of foot abnormalities with increasing free-choice time for elephants in North American zoos. The differing results might be due to the fact that within the North American population, the alternative for free choice time is much more time outdoors (time free choice: 16.0%, time outdoors: 55.1%, time indoors: 28.9%), whereas within the European population the elephants spend alternatively much more time indoors (time free choice: 21.3%, time outdoors: 25.2%, time indoors: 53.4%).

The time the elephants spent outdoors on the day of examination was recorded to consider seasonal differences, since it was not possible to visit all facilities in the same season. In the bivariate correlation, a significant, but small effect on the ParSev Score was found, indicating that elephants that spent more time outdoors had a lower score. Reasons for a longer time outdoors could be that the zoo was either visited in summer, when elephants usually have the longest time outdoors or that the zoo generally provided longer outdoor stays.

The regression model with ParSev Scores revealed that elephants that were kept together with immediate relatives (parents, offspring or siblings) showed less or less severe foot problems. In the wild, female elephants and their offspring build matriarchic herds consisting of closely related individuals, whereas males leave the group at the age of puberty (Vidya and Sukumar 2005). So for females, having an immediate relative in the group, displays the natural social environment and should therefore help to maintain adequate exercise through social interaction, which is suggested as being beneficial for the foot health (Roocroft and Oosterhuis 2001, West 2001).

A similar effect may be underlying for the group size (Lehnhardt 2006). The mean size of wild Asian elephant herds in southern India lies

between 5.8 and 8.8 depending on the season (Sukumar 2003). In the European zoo population, a herd consisted of 3.4 elephants on average. Through bivariate correlation, a significant correlation was found, indicating that elephants in larger groups had lower ParSev Scores.

To maintain a preferable body and foot condition, adequate exercise is advised by several authors (Fowler 2001b, Schwammer 2001, West 2001). Since the environment of captive elephants is often not sufficiently exercise-inducing, Roocroft and Oosterhuis (2001) recommend at least one to two hours of keeper-supervised walking per day. In the present study, 15.6% of the examined elephants were exercised in this way. In free contact, the elephants were walked next to the keeper either through or outside of their enclosure. In protected contact, the elephants were sent to different points in their enclosure. Using bivariate correlation, a small effect was found between hours of exercise per week and ParSev Score, indicating that elephants that were exercised more had higher ParSev Scores. This correlation opposes our expectation and contradicts the results from Lewis et al. (2010). Although the effect was only small, it should be considered to exercise elephants, preferably stimulated by an adequate social structure and a varied feeding enrichment instead of induced by keepers, since this would imitate natural movement patterns better. Probably keeper-induced exercise is especially implemented by institutions with rather suboptimal conditions (e.g. small enclosures, low social interaction within the herd) to compensate for these deficiencies, and is therefore a proxy indicator for these other conditions.

4.4 | Enclosure

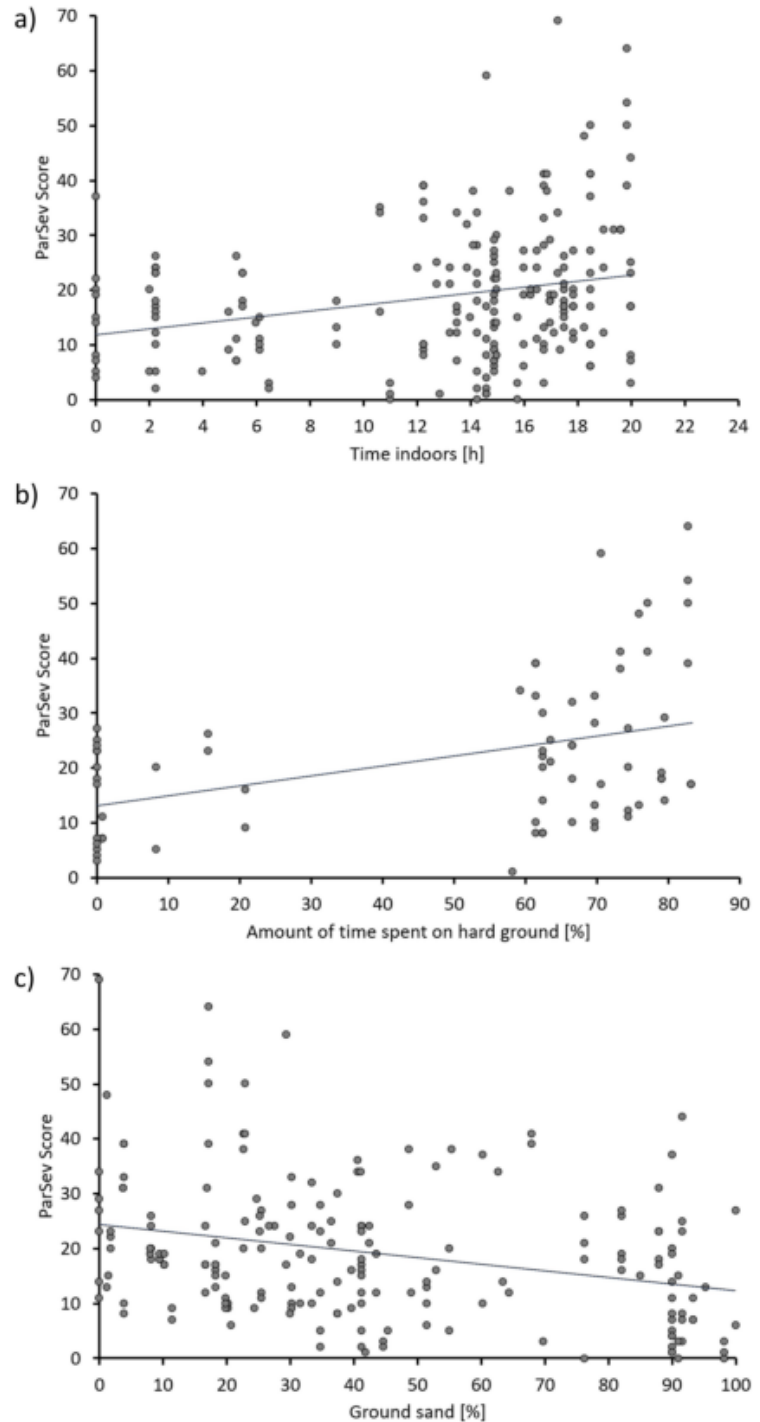
Time spent on exclusively hard ground is the third and last variable with a significant result in more than one statistical test, whereby a higher amount of time spent on hard ground led to higher ParSev Scores (Figure 3b). The bivariate correlation revealed a medium effect and there was also a significant correlation in the linear regression model with mean values for the institutions. Analogous to Miller et al.

(2016), only enclosures with 100% hard ground (concrete, asphalt, rocks or tiles) were considered for the calculation of the amount of time the elephant spent in this area. This allows a comprehensible statistical analysis, since the elephant actually stands on hard ground without a soft-floored alternative. The problem in this method is that there are few data points, since most elephants were kept in enclosures with mixed floor types (63.4%), and that these data points are bimodally distributed (either very low or very high values, but no data points between 25% and 55% of time spent on hard ground). Additionally, the time spent on hard ground is related to the time spent indoors, since 100% hard ground is usually only used for indoor and not for outdoor enclosures. Hard ground is one of the main factors presumed to lead to foot problems (Gage 2001, West 2001) and has already been identified as a risk factor by Haspeslagh et al. (2013) and Miller et al. (2016).

Haspeslagh et al. (2013) also identified sand as risk factor, which is usually evaluated as beneficial for the foot health since this substrate yields, allows digging and is preferably used for lying down, which relieves the feet (Holdgate et al. 2016, Roocroft and Oosterhuis 2001, Schwammer 2001, Williams, Bremner-Harrison, Harvey, Evison and Yon 2015). In the present study, sand was indeed identified as beneficial factor for the foot health, since a higher amount of sand flooring correlated significantly with lower ParSev Scores (Figure 3c). In contrast to the amount of time on hard ground, data concerning sand flooring is continuously distributed, and therefore well apt for quantitative analysis. This emphasizes the importance of supplying considerable amounts of sand flooring in modern elephant enclosures.

For the amount of grass in the enclosure, a small effect in the bivariate correlation was found, indicating higher ParSev Scores when there was a higher amount of grass in the enclosure. This result should be evaluated with caution since only a quarter of the elephants had grass in their enclosure. Grass being a natural ground, we would have expected a positive effect on foot health. Haspeslagh et al. (2013) found no significant effect of grass on

Figure 3 Relation between ParSev Score of captive Asian elephants (*Elephas maximus*) and a) the time spent indoors, b) the amount of time spent on hard ground, and c) the amount of sand flooring in the enclosure



foot health. One reason for the negative effect could be waterlogging if the natural grass flooring drains worse than for example sand flooring. This would correspond to the higher ParSev Score in more frequently washed or wet feet, but nevertheless presents a rather vague explanation. Probably, the amount of

grass goes hand in hand with other factors negatively influencing foot health.

Whereas most previous studies did not reveal a significant effect of the enclosure size on foot health (Harris et al. 2008, Lewis et al. 2010), a larger area was significantly correlated with lower ParSev Scores in the present analysis. Showing a medium effect in

the bivariate correlation, indoor area seems to be more influential than outdoor area, which was not significant. There was a significant but small effect of the mean area and the area per animal, which can be explained by the contribution of the indoor area in these variables. The mean indoor size was 385 m² for a mean group size of 2.9 animals, which surpasses the EAZA and BIAZA management guidelines requiring a minimum of 200 m² for four elephants (EAZA 2005, Walter 2010). A large indoor size, especially when structured and enriched, allows and encourages activity, which is considered beneficial for foot health (Roocroft and Oosterhuis 2001, West 2001). The importance of the indoor enclosure size becomes particularly apparent when considering time budgets of captive elephants. An elephant spends approximately three to four hours per 24 hours sleeping in lying position (Holdgate et al. 2016, Walsh 2017) but is kept inside for 12.8 hours on average. Hence, there is considerable time left for activity, requiring a certain amount of space.

4.5 | Diet

The only variable showing a strong effect in the bivariate correlation was the amount of browse provided per day per unit metabolic body weight. A higher amount of browse is related with lower ParSev Scores, indicating a better foot health condition. Since most zoos either fed browse irregularly depending on availability, or could not quantify the amount provided per elephant, there are very few data points and the result must be interpreted with caution. Nevertheless, the influence of browse is worth considering since long branches are crushed using the trunk and the front feet for fixation. This process might help wearing cuticles, nails and pads in a natural way while also stimulating blood circulation in the foot, and might therefore prevent the development of pathological lesions. To test this assumption, we correlated the amount of browse provided per day per unit metabolic body weight separately with the ParSev Score of the front respectively hind feet, hypothesizing that browse only influences the front feet which are involved in the crushing process. Both correlations were significant, so we could not

prove the assumption (front feet: $r_s = -0.54$, $p = 0.001$, hind feet: $r_s = -0.50$, $p = 0.002$). Another possible explanation for the significant correlation would be that precise data on the amount of branches and the weight of the elephants was only provided by zoos with a generally advanced husbandry level and consequently lower ParSev Scores. For a general discussion of indicators of advanced husbandry standards, see below. To further examine the relation between browse and foot health, a larger data set would be necessary.

There were also small effects in the bivariate correlations of the amounts of grass, silage and vegetables provided per day per unit metabolic body weight and the ParSev Score, indicating lower foot scores when higher quantities were fed. Again, precise data was not available for all zoos which could be influential on the resulting correlation. An elephant's diet should base on high-fiber roughage to avoid obesity, which might negatively influence foot health (Hatt and Clauss 2006, Sadler 2001). In most collections, this is supplemented by additional components. In this context, grass, silage and vegetables might actually have a positive effect on the foot health especially when replacing easily digestible energy sources like fruits, bread, cereals or concentrated pellets.

Biotin has been identified as beneficial for the hoof horn quality in horses (Geyer and Schulze 1993) and is therefore also used in elephants assuming similar effects. Benz (2005) showed that supplemented elephants reached higher biotin blood concentrations than non-supplemented animals, and hence deduced a good intestinal absorption. But so far, the actual influence of supplemented biotin on the elephant's foot health has not been proven. In the present study, a significant but small effect was found between the amount of biotin supplied per elephant per day and the ParSev Score, indicating higher foot scores with increasing biotin doses. We suggest that this is not due to a negative effect of biotin on the foot health but because it is fed especially to elephants with poor foot condition. A long-term study analyzing the changes in the foot health with varying biotin doses while other parameters (such as husbandry, foot care and

diet) remain unchanged would be necessary to further investigate this topic.

4.6 | Climate

No significant correlation was found between the ParSev Score and climate-related variables like the total annual precipitation and the annual average temperature. The regression model with single nail values identified two countries with significantly lower ParSev Scores. Since there was only a small number of zoos included in both countries, the significant result was rather due to general conditions in these institutions and not because of topographical or climatic aspects.

4.7 | Holistic consideration

The easiest-to-interpret and desired result of these analyses would have been to identify one or two risk factors which show a significant result in every statistical test and therefore provide a tangible starting point for future improvement of foot health. But in fact, we found 30 different variables with significant results, most of which being only significant in one of the statistical tests and showing rather small effect sizes. Therefore, it might be reasonable to consider the overall concept instead of trying to evaluate which of these factors might be the most important one. Showing the interrelations of several selected variables, the principle component analysis appears suitable to provide a basis for this kind of consideration. The biplot (Figure 1) shows that eigenvectors indicating a rather advanced husbandry level point roughly in the same direction and are therefore related with each other. These would be, amongst others, enclosure sizes, time with free choice about in- or outdoor stay, sand flooring and group size. Opposite to these representatives of preferable husbandry conditions, there are factors associated with potentially problem causing conditions like hard flooring, time spent indoors, stereotypies and age. Amongst these, there is also the eigenvector representing the ParSev Score and therefore pathological lesions of feet. So, generally poorer husbandry conditions seem to lead to more or more severe pathological lesions, and to positively

influence foot health, it might not be sufficient to change only one factor, but to revise the overall concept of elephant husbandry and care.

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APPENDICES

- Appendix 1 Herd survey on influencing factors on the foot health of Asian elephants (*Elephas maximus*).
- Appendix 2 Individual survey on influencing factors on the foot health of Asian elephants (*Elephas maximus*).
- Appendix 3 Independent variables and statistical analysis of influencing factors on the foot health of Asian elephants (*Elephas maximus*).

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APPENDIX 1**Herd survey on influencing factors on the foot health of Asian elephants (*Elephas maximus*)**

Institute: _____ (one survey for each group)

> Herd

How many animals do you keep? [male/female] _____

How many groups do you keep and how are they composed? [x.x] _____

Number of groups: _____

Composition: _____

How long have they been in that composition? _____

Are there any other compositions and how long do they stay in them? (e.g. during pregnancy, musth) _____

Compositions: _____

Duration: _____

Contact: _____

☐ Hands-on

☐ Protected contact

☐ No contact

> Enclosure

How big is the outdoor area [m²]? _____

How big is the indoor area [m²]? _____

Daily schedule of outdoor and indoor stay? _____

Spring: _____ h indoors _____ h outdoors ☐ free choice

Summer: _____ h indoors _____ h outdoors ☐ free choice

Autumn: _____ h indoors _____ h outdoors ☐ free choice

Winter: _____ h indoors _____ h outdoors ☐ free choice

What ground type do they have? [%] _____

Outdoor:

☐ Sand [____%] (hard/soft)

☐ Concrete [____%]

☐ Grass [____%]

☐ Dirt [____%]

☐ Rubber mats [____%]

☐ Asphalt [____%]

☐ Straw [____%]

☐ Rocks [____%]

☐ Tiles [____%]

☐ Other: _____ [____%]

Indoor:

☐ Sand [____%] (hard/soft)

☐ Concrete [____%]

☐ Dirt [____%]

☐ Rubber mats [____%]

☐ Asphalt [____%]

☐ Straw [____%]

☐ Tiles [____%]

☐ Other: _____ [____%]

What is the cleaning interval?

Outdoor:

Indoor:

Do you have any bathing areas in the indoor/outdoor enclosure?

Indoor:

Outdoor:

☐ Yes | ☐ No

☐ Yes | ☐ No

How many and how large are they?

Number:

Size [m²] or [m x m]:

Depth:

How often do the animals use it in average per day?

How often do you change the pool water?

Do you have any sand- or clay bathing areas and how often do you exchange them?

☐ Yes | ☐ No

Exchange interval:

How many and how large are they?

Number:

Size [m²]:

Do you enrich the enclosure and how?

☐ Yes | ☐ No

List of enrichment:

> Exercise and activities

Do you exercise your animals?

☐ Yes | ☐ No

Individually or as group?

☐ Individually | ☐ Group

How often per week and how long per session?

Frequency:

Duration:

What kind of exercise?

> Feeding

What is your feeding schedule per day?

Do you feed hay ad libitum?

☐ Yes | ☐ No

If not, how often do you feed? _____

What else do you feed, when and how much per animal?

What:

When:

How much:

Where do you feed?

Number of feeding places:

Distribution:

Do you enrich the feeding process and if so how?

☐ Yes | ☐ No

How:

Do you supplement Biotin?

☐ Yes | ☐ No

Frequency:

Dose:

Do you supplement anything else?

What:

Dose:

Frequency:

> Foot care

Is there a schedule for cleaning the feet?

☐ Yes | ☐ No

Interval:

How do you clean the feet?

Tools:

Do you check the feet regularly for medical issues?

☐ Yes | ☐ No

Interval:

Do you undertake foot care and how often?

☐ Yes | ☐ No

Interval:

Do you record your foot care/the status of the feet and if yes, how?

☐ Yes | ☐ No

☐ Written | ☐ Photographically | ☐ By videotape

Do you perform a scheduled foot care irrespective of the current occurrence of foot pathologies?

☐ Yes | ☐ No

Checklist

Please list the steps you are performing when undertaking routine foot care:

Tools used for those:

Who is undertaking the foot care?

☐ Keeper

☐ Veterinarian

☐ Blacksmith

☐ Other: _____

Does the person have a special training for taking care of elephant feet?

☐ Yes | ☐ No

If so, what kind of training?

Is it always the same person undertaking the foot care per animal?

☐ Yes | ☐ No

> Elephant team

How many keepers care for the elephants?

How many years of experience do they have with elephants?

How many years of experience with elephants does the head keeper have?

> Additional information

Did you change anything about the enclosure during the last year and have you noticed any impact on the elephant's foot health?

Enclosure change: ☐ Yes | ☐ No

Kind of change:

Impact on foot health: ☐ Yes | ☐ No

Kind of impact:

APPENDIX 2**Individual survey on influencing factors on the foot health of Asian elephants (*Elephas maximus*)**

Institute:

Group:

Name of the animal:

> General information

Date of birth: _____

Sex: ☐ Male | ☐ Female

Where and when did the animal live before its time in your zoo?

How much does the animal weigh? _____ kg (☐ weighed | ☐ estimated)

Have there been any noticeable changes in weight during the past 5 years and do you know why?

2011:

2012:

2013:

2014:

2015:

2016:

What is the animal's dominance status in the herd?

Does the animal show aggressive behaviour?

☐ Yes | ☐ No

towards whom:

How active is the animal? [% of time in each enclosure]

Movement in outdoor enclosure: _____%

Movement in indoor enclosure: _____%

What kind of enrichment does the animal use?

How cooperative is the animal while actions like foot care (on a scale from 0 to 4)?

☐ 0 (foot care not possible)☐ 1 (refuses to cooperate often but possible with difficulties)☐ 2 (refuses sometimes)☐ 3 (cooperates most of the times without many problems)☐ 4 (cooperates all the time)

Do you chain the animal regularly and if so how long per day?

☐ Yes | ☐ No

Duration: _____

Do you have any special information about the animal (feeding, exercise)?

> Health status

 Does the animal have any chronic diseases?

☐ Yes | ☐ No

 What kind of diseases?

 How do you treat them?

 Does the animal show any stereotypic behaviour and if yes since when and how many hours per day?

☐ Yes | ☐ No since: _____ hours per day: _____

 What kind of stereotypical behaviour does the animal show?

- | | |
|--------------------------------------------------------------------------|------------------------------------------------------------------|
| <input type="checkbox"/> Weaving (shifting weight from side to side) | <input type="checkbox"/> Nodding (moving head from side to side) |
| <input type="checkbox"/> Pacing (walking without destination vertically) | <input type="checkbox"/> Head bobbing (moving head vertically) |
| <input type="checkbox"/> Swaying (shifting weight forwards and back) | <input type="checkbox"/> Foot lifting |
| <input type="checkbox"/> Trunk swinging | <input type="checkbox"/> Other: _____ |

 What kind of foot problems did the animal have in the past and when did they occur?

 What is the current status of its feet? (any medical issues? How are they treated?)

Nails:

- | | | |
|-----------------------------------------|--------------------------------------------------|---------------------------------------------------------|
| <input type="checkbox"/> Nails too long | <input type="checkbox"/> Nail cracks | <input type="checkbox"/> Overgrown nail cuticle |
| <input type="checkbox"/> Fluid pockets | <input type="checkbox"/> Nail abscess | <input type="checkbox"/> Space between nails too narrow |
| <input type="checkbox"/> Paronychia | <input type="checkbox"/> Horn growth abnormality | <input type="checkbox"/> Other: _____ |

Pad:

- | | | | |
|------------------------------------|-----------------------------------------|------------------------------------|---------------------------------------|
| <input type="checkbox"/> Overgrown | <input type="checkbox"/> Lesions: _____ | <input type="checkbox"/> Abscesses | <input type="checkbox"/> Other: _____ |
|------------------------------------|-----------------------------------------|------------------------------------|---------------------------------------|

Treatment:

 Foot measurement:

[cm]	Left front foot	Right front foot	Left hind foot	Right hind foot
Circumference:				
Length diameter (cranial to caudal)				
Width diameter (medial to lateral)				

APPENDIX 3

Independent variables and statistical analysis of influencing factors on the foot health of Asian elephants (*Elephas maximus*)

Variable	Description	Character	n	Spearman correlation/ Point-biserial correlation to ParSev Score		Included in multivariable linear regression models			Included in PCA
				r _s / r _{pbi}	p-value	Models with individual values	as random effect 'zoo'	Model with mean values	
I. Individual characteristics									
Age	Age on the day of examination	Continuous	204	0.07	0.304	Yes	No	No	Yes
BCS	Body condition score according to Schiffmann et al. (2018)	Ordinal	204	-0.02	0.806	Yes	No	No	Yes
Body mass	Body mass of weighed elephants	Continuous	129	-0.05	0.606	Yes	No	Yes* p = 0.022	No
Chronic disease	Occurrence of a chronic disease	Dichotomous	204	0.13†	0.061	Yes* p = 0.004§	No	No	No
- Arthrosis	Occurrence of arthrosis	Dichotomous	204	0.07†	0.354	No	No	No	No
- Blindness	Occurrence of blindness	Dichotomous	204	-0.03†	0.630	No	No	No	No
- Gastrointestinal	Occurrence of a chronic gastrointestinal disease	Dichotomous	204	0.09†	0.219	No	No	No	No
- Heart	Occurrence of a chronic heart disease	Dichotomous	204	> -0.01†	0.967	No	No	No	No
- Malalignment	Occurrence of leg or foot malalignment	Dichotomous	204	0.11†	0.107	No	No	No	No
- Skin	Occurrence of a chronic skin disease	Dichotomous	204	0.16†	0.021*	No	No	No	No
- Trunk paralysis	Occurrence of trunk paralysis	Dichotomous	204	-0.05†	0.521	No	No	No	No
- Urinary reproductive	Occurrence of a chronic disease of the urinary or reproductive tract	Dichotomous	204	0.01†	0.938	No	No	No	No
Dominance	Dominance of the elephant in the group	Ordinal	204	-0.06	0.418	Yes	No	No	No
No. places	Number of places the elephant lived in	Continuous	204	0.11	0.130	Yes	No	No	No
Origin	Born in Asia or in a European/American zoo	Dichotomous	204	-0.06†	0.423	Yes	No	No	No
Sex	Sex	Dichotomous	204	-0.15†	0.031*	Yes* p ₁ = 0.001‡ p ₂ = 0.001§	No	No	No
Sire	Sire of the animal	Nominal	204	/	/	Yes* p _{Male A} = 0.001‡ p _{Male B} = 0.033‡	No	No	No
Stereotypies	Stereotypic behavior in hours per day	Continuous	204	0.01	0.927	Yes	No	No	Yes (log)
- Head bobbing	Stereotypic head bobbing in hours per day	Continuous	204	0.12	0.100	No	No	No	No
- Nodding	Stereotypic nodding in hours per day	Continuous	204	0.15	0.035*	No	No	No	No
- Pacing	Stereotypic pacing in hours per day	Continuous	204	0.08	0.244	No	No	No	No
- Swaying	Stereotypic swaying in hours per day	Continuous	204	0.01	0.896	No	No	No	No
- Trunk swinging	Stereotypic trunk swinging in hours per day	Continuous	204	0.04	0.537	No	No	No	No
- Weaving	Stereotypic weaving in hours per day	Continuous	204	-0.11	0.109	No	No	No	No
Walking activity	Mean daily activity of the elephant	Continuous	197	-0.09	0.216	Yes	No	No	Yes

Variable	Description	Character	n	Spearman correlation/ Point-biserial correlation to ParSev Score		Included in multivariable linear regression models			Included in PCA
				r _s / r _{pbi}	p-value	Models with individual values	as random effect 'zoo'	Model with mean values	
II. Foot care									
Care score	Care condition of the foot	Ordinal	191	0.20	0.004*	No	No	No	Yes
Contact	Direct or protected contact	Dichotomous	204	-0.13†	0.056	Yes	Yes	Yes	No
Cooperativity	Cooperativity of the elephant during foot care	Ordinal	204	-0.19	0.006*	Yes	No	No	Yes
Frequency foot care	Frequency of foot care	Ordinal	193	-0.08	0.250	Yes	Yes	Yes	Yes
Foot care concept	Schedule of foot care	Ordinal	204	0.06	0.367	Yes	Yes	Yes	No
Pad score	Surface texture of the pad	Ordinal	204	0.16	0.019*	No	No	No	Yes
Record foot care	Record of foot care	Nominal	204	/	/	Yes	Yes	Yes	No
Theoretical approach foot care	Knowledge about the steps of a complete foot care	Ordinal	204	-0.04	0.554	Yes	Yes	Yes	No
Training keepers	Training of keepers concerning foot care	Dichotomous	204	-0.08†	0.241	Yes	Yes	Yes	No
- Consultant	Consultant for foot care training	Dichotomous	204	-0.05†	0.475	No	No	No	No
- Workshop	Participation in foot care workshop	Dichotomous	204	-0.08†	0.257	No	No	No	No
- Zoo cooperation	Visits of different zoos by keepers to learn from other teams	Dichotomous	204	0.01†	0.886	No	No	No	No
Washing	Frequency of foot washing	Ordinal	204	-0.16	0.025*	No	No	No	No
Wet feet	Frequency of feet being wet due to washing or pool usage	Ordinal	204	-0.15	0.030*	No	No	No	No

Variable	Description	Character	n	Spearman correlation/ Point-biserial correlation to ParSev Score		Included in multivariable linear regression models			Included in PCA
				r _s / r _{pbi}	p-value	Models with individual values	as random effect 'zoo'	Model with mean values	
III. Management									
Age group	Mean age of the group	Continuous	204	0.07	0.341	Yes	Yes	Yes	Yes
Chaining	Hours per day the elephant is chained	Continuous	204	0.06	0.382	Yes	No	Yes	No
Current time outdoors	Hours per day spent outdoors on examination day	Continuous	204	-0.14	0.041*	Yes	Yes	Yes	No
Elephant team	Keepers caring exclusively for elephants	Dichotomous	204	-0.11†	0.116	Yes	Yes	Yes	No
Enrichment kinds	Number of different enrichment kinds	Continuous	204	-0.08	0.234	Yes	Yes	Yes	No
Enrichment tools	Number of different enrichment tools	Continuous	204	0.02	0.736	Yes	Yes	Yes	Yes
Exercise	Time of the week the elephant gets walking exercises by the keepers	Continuous	204	0.16	0.024*	Yes	Yes	Yes	No
Experience	Number of years of experience of the most experienced keeper	Continuous	204	-0.04	0.580	Yes	Yes	Yes	Yes
Free choice availability	Possibility for the elephant to choose between in- and outdoor stay	Dichotomous	204	-0.16†	0.022*	No	No	No	No
Group size	Number of elephants in the group	Continuous	204	-0.16	0.020*	Yes	Yes	Yes	Yes
Keepers	Number of keepers caring for the elephants	Continuous	204	-0.14	0.051	Yes	Yes	Yes	Yes
Keeper per animal	Number of keepers per elephant for exclusive elephant teams	Continuous	161	0.02	0.776	Yes	Yes	Yes	No
Relatives	Presence of relatives in the group	Dichotomous	204	-0.07†	0.300	Yes* p = 0.046§	No	No	No
Time free choice	Hours per day the elephant can choose between in- and outdoor stay	Continuous	204	-0.22	0.001*	Yes	Yes	Yes	Yes (log)
Time indoors	Hours per day the elephant spends inside	Continuous	204	0.25	< 0.001*	Yes	Yes	Yes* p = 0.002	Yes
Time outdoors	Hours per day the elephant spends inside	Continuous	204	0.09	0.223	Yes	Yes	Yes	No

Variable	Description	Character	n	Spearman correlation/ Point-biserial correlation to ParSev Score		Included in multivariable linear regression models			Included in PCA
				r_s / r_{pbi}	p-value	Models with individual values	as random effect 'zoo'	Model with mean values	
IV. Enclosure									
Age enclosure	Age of the enclosure in the year of visit	Continuous	185	0.04	0.551	No	No	No	No
Area per animal	Area per animal	Continuous	192	-0.15	0.038*	Yes	Yes	Yes	Yes (log)
Ground asphalt	Amount of asphalt in the enclosure	Continuous	188	0.10	0.160	No	No	No	No
Ground bark	Amount of bark in the enclosure	Continuous	188	-0.08	0.253	No	No	No	No
Ground concrete	Amount of concrete in the enclosure	Continuous	188	0.05	0.469	No	No	No	No
Ground grass	Amount of grass in the enclosure	Continuous	188	0.15	0.041*	No	No	No	No
Ground rocks	Amount of rocks in the enclosure	Continuous	188	0.07	0.318	No	No	No	No
Ground rubber	Amount of rubber in the enclosure	Continuous	188	0.03	0.705	No	No	No	No
Ground sand	Amount of sand in the enclosure	Continuous	188	-0.31	< 0.001*	Yes	Yes	Yes	Yes
Ground soil	Amount of soil in the enclosure	Continuous	188	0.13	0.086	No	No	No	No
Ground tiles	Amount of tiles in the enclosure	Continuous	188	-0.04	0.583	No	No	No	No
Hard ground sum	Amount of hard ground types in the enclosure	Continuous	188	0.13	0.084	Yes	Yes	Yes	Yes
Indoor area	Size of indoor area	Continuous	192	-0.30	< 0.001*	Yes	Yes	Yes	Yes (log)
Mean area	Mean area	Continuous	192	-0.26	< 0.001*	Yes	Yes	Yes	Yes (log)
Outdoor area	Size of outdoor area	Continuous	192	-0.11	0.127	Yes	Yes	Yes	Yes (log)
Time hard ground	Amount of time spent on exclusively hard ground	Continuous	71	0.39	0.001*	No	No	Yes* p = 0.001	No

Variable	Description	Character	n	Spearman correlation/ Point-biserial correlation to ParSev Score		Included in multivariable linear regression models			Included in PCA
				r _s / r _{pbi}	p-value	Models with individual values	as random effect 'zoo'	Model with mean values	
V. Diet									
Biotin	Amount of biotin fed	Continuous	192	0.19	0.008*	No	No	Yes	Yes (log)
Bran	Amount of bran fed relative to MBW	Continuous	184	0.03	0.716	No	No	Yes	No
Bread	Amount of bread fed relative to MBW	Continuous	149	0.06	0.498	No	No	Yes	No
Browse	Amount of browse fed relative to MBW	Continuous	37	-0.60	< 0.001*	No	No	Yes	No
Cereals	Amount of cereals fed relative to MBW	Continuous	173	-0.07	0.391	No	No	Yes	No
Fruits	Amount of hay fruits relative to MBW	Continuous	100	-0.12	0.232	No	No	Yes	No
Grass	Amount of grass fed relative to MBW	Continuous	114	-0.22	0.016*	No	No	Yes	No
Hay	Amount of hay fed relative to MBW	Continuous	42	0.12	0.467	No	No	Yes	No
Pellets	Amount of pellets fed relative to MBW	Continuous	136	-0.10	0.267	No	No	Yes	No
Silage	Amount of silage fed relative to MBW	Continuous	196	-0.24	0.001*	No	No	Yes	No
Straw	Amount of straw fed relative to MBW	Continuous	155	0.08	0.322	No	No	Yes	No
Vegetables	Amount of hay vegetables relative to MBW	Continuous	88	-0.24	0.027*	No	No	Yes	No
VI. Climate									
Country	Country of residence	Nominal	204	/	/	Yes* p _{Country1} = 0.009‡ p _{Country2} = 0.010‡	No	No	No
Mild months	Number of months with an average temperature of at least 10°C	Continuous	204	0.08	0.228	No	No	No	No
Precipitation	Total annual precipitation	Continuous	204	-0.09	0.208	No	No	No	Yes
Temperature	Annual average temperature	Continuous	204	0.08	0.279	No	No	No	Yes (log)

* p-values < 0.05

/ not correlated due to nominal character of the variable

† for dichotomous variables instead of Spearman's rho (r_s) the point-biserial correlation coefficient r_{pbi} was calculated

‡ regression to single nail values [0-3]

§ regression to ParSev Score

(log) variable was log-transformed before being added to the model

PCA principal component analysis

MBW metabolic body weight

**Foot care in Asian elephants (*Elephas maximus*)
in European zoos**

Paulin Wendler*, Nicolas Ertl*, Michael Flügger, Endre Sós, Marcus Clauss, Jean-Michel Hatt

*these authors contributed equally

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Research Article

Foot care in Asian elephants (*Elephas maximus*) in European zoos**Paulin Wendler^{*1}, Nicolas Ertl^{*1}, Michael Flügger², Endre Sós³, Marcus Clauss¹, Jean-Michel Hatt¹*****these authors contributed equally**¹ Clinic for Zoo Animals, Exotic Pets and Wildlife, Vetsuisse Faculty, University of Zurich, Switzerland² Tierpark Hagenbeck, Hamburg, Germany³ Budapest Zoo & Botanical Garden, Hungary

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Keywords: Asian elephant, *Elephas maximus*, foot care, foot health, ParSev Score, pedicure, tools**Abstract**

The foot health of captive Asian elephants (*Elephas maximus*) is a common concern in zoological institutions. Offering adequate husbandry conditions is a common approach to improve foot health in captivity. Additionally, foot care is implemented to treat and prevent pathological lesions. There are different approaches for the management of foot care, which vary for example in contact type, frequency, record-taking and equipment. By interviewing elephant keepers, recording video footage of a routine foot care procedure and taking photographs of the elephants' feet, data was collected of 243 Asian elephants in 69 European institutions. Based on this data, a general overview of the applied foot care methods was obtained, and the influence of different approaches on the foot health status was analysed. Nearly all institutions (97.0%) performed a more or less regular foot care in their elephants, but only 16.7% did so under a prophylactic (as opposed to reactive) regime. Whereas the contact type had no significant influence on the foot health ($p = 0.056$), a higher foot care frequency was linked to better foot health conditions ($p = 0.009$). Elephant staff showed a strong theoretical knowledge base of principle pedicure steps, which are cutting cuticles, widening interdigital spaces, shortening nails, and attending pads (75.8% named four of four steps). However, a complete practical treatment of the relevant structures (cuticles, interdigital spaces, nail length, surface and defects) was only carried out in 29.4% of the cases with necessity for treatment. The most common tools were hoof knives, rasps and electric grinders. The usage of angle grinders was linked to more, or more severe, foot problems ($p = 0.031$) compared to the usage of manual tools. In particular, it was associated with a higher frequency of solar horn defects ($p = 0.049$), which are moderate pathological lesions, and with a higher frequency of too-narrow interdigital spaces ($p = 0.015$), which are a concern of foot care. This leads to the recommendation to rather use hoof knives and rasps instead of angle grinders.

Introduction

In Europe, Asian elephants (*Elephas maximus*) are kept in 97 zoological institutions (Damen and Van Wees 2016). Although elephant husbandry and management are constantly improving, for example by providing larger enclosures and refraining from tethering, foot health problems are still very common (Harris et al. 2008, Haspeslagh

et al. 2013, Miller et al. 2016, Wendler et al. 2019). Besides offering improved husbandry conditions, the common approach to treat and prevent foot problems in elephants remains manual foot care typically provided by keepers (Lehnhardt 2006, Roocroft and Oosterhuis 2001).

The treatment of existing pathological lesions such as nail cracks and abscesses usually comprises a mechanical debridement of necrotic

tissue and a shortening of structures to decrease pressure on them. This is often combined with local drug delivery (Rutkowski et al. 2001b, West 2001). In theory, foot care is also prophylactically implemented to prevent pathological lesions of feet. There are various opinions and philosophies on how to perform adequate foot care, since there is no “gold standard”. Instead, the approach needs to be adapted to each elephant’s circumstances, which includes aspects such as age, housing and level of training (Roocroft and Oosterhuis 2001).

In general, there are four different structures of interest when approaching foot care: I) cuticles, which should be attended if they are overgrown, frayed, attached to the nail or contain fluid pockets, II) interdigital spaces, which should be trimmed at least one finger wide so that moisture does not accumulate, and to avoid the development of abnormal pressures between the nails, III) nails, of which nail surface (dorsal wall segment) and nail sole (distal part of the nail) are to be considered and which should be kept in natural shape and short to prevent abnormal pressure due to ground contact when standing, and IV) pads, which can be affected by foreign bodies, overgrowth and the formation of pockets and should be attended in these cases (Kock 1994, Roocroft and Oosterhuis 2001).

Besides the frequency of foot care and the question whether and how to trim the pad, one main topic of differing opinions is which tools are to be used. Whereas Roocroft and Oosterhuis (2001) recommend the usage of hoof knives and rasps and advise against using power tools, for Hughes and Southard (2001) the benefits of power tools outweigh the disadvantages when applied with caution. Negative aspects of using power tools are the risk of cutting too deep and damaging healthy tissue as well as distraction of the elephant by noise and vibration. On the other hand, they facilitate the execution of foot care, fastening the process significantly, and might therefore enable the care takers to attend the elephants’ feet more frequently. Yet, the actual effect of the usage of power tools on the foot health and foot care condition is still unknown.

The aim of this study was to describe and discuss preventive pedicure methods applied in Asian elephants in European zoos and to link them to the presence of pathological lesions of feet, care issues and the general foot health.

Material and methods

Ethics statement

The project was authorised by the management of each participating institution. Additionally, it was approved by the Elephant Taxon Advisory Group (TAG) of the European Association of Zoos and Aquaria (EAZA) and the British and Irish Association of Zoos and Aquariums (BIAZA). The study was non-invasive. The presentation of a routine foot care was part of the regular pedicure schedule in each zoo.

Data collection

Between August 2016 and July 2017, 69 zoos that are members of the European Endangered Species Programme (EEP) were visited personally by one of two project veterinarians (Wendler et al. 2019). In each institution, the elephant staff was interviewed concerning various aspects of their foot care programme (Table 1), video footage was taken of a routine foot care procedure and, to detect pathological lesions of feet and the general foot health status, photographs were taken of each elephant’s nails and pads. Due to the necessity of a certain level of training, only elephants with at least 5 years of age were included in the study. For video recordings and pictures, a Panasonic Lumix DMC-GF1 or a Sony Cyber-Shot DSC H9 were used, respectively, if necessary, under light supplementation by a Neewer Flashgun FC100.

Analysing the video footage of each institution, the necessity of foot care of five areas was evaluated at the beginning of the footage, i.e. before pedicure was applied. These five areas were: cuticles, interdigital spaces, nail length, nail surface and nail defects (Table 2). At the end of the footage, i.e. after foot care, the completeness of the treatment concerning these five areas was assessed (Table 3). Additionally, it was observed whether the pad was trimmed completely, partly, whether only sulci were cut out or whether it was not attended at all (Fig. 1). For all areas including the pad, the tools used for processing were recorded.

In the same animals, the state of all feet (before the respective foot care) was documented by photography. The evaluation of clinical pathology using the photographic documentation of the feet (Wendler et al. 2019), as well as the development of a foot health score (Ertl et al. 2019) have been described previously. The pictures of the feet were examined regarding

Table 1. Variables concerning foot care in Asian elephants (*Elephas maximus*) recorded by interviewing the elephant teams of 69 European collections

Variable	Description	Values
Contact	Contact type the elephants are worked with	1 = Direct contact (hands on) 2 = Protected contact
Cooperativity	Cooperativity the elephant shows while undertaking foot care, evaluated by the keepers	1 = Foot care not possible 2 = Refuses to cooperate often, but foot care possible with difficulties 3 = Refuses sometimes 4 = Cooperates most of the time without many problems 5 = Cooperates all the time
Concept	Concept of foot care	1 = Prophylactic complete regular foot care irrespective to occurring pathological lesions 2 = Reactive non-regular foot care, only if pathological lesions occur 3 = No foot care
Frequency	Frequency of foot care	1 = Never 2 = Every 6 - 12 months 3 = Every 4 - 5 months 4 = Every 2 - 3 months 5 = Monthly 6 = Every 2 - 3 weeks 7 = Weekly
Record	Record of foot care and foot status	1 = Not recorded 2 = Written 3 = Photographically 4 = By video footage
Theoretical approach	Number of the following principle steps of foot care, that could be named by the keepers: - cutting cuticles - widening interdigital space - shortening nails - attending pad	[0 - 4]

pathological lesions, care issues and pad surface (Wendler et al. 2019). Each pathological lesion was associated with a score between 0 and 3 according to its severity; the general foot health score of an elephant was determined by squaring and summarising each nail's and pad's score and was called particularised severity score (ParSev Score) (Ertl et al. 2019). In consequence, a higher ParSev Score arose as a result of more or more severe pathological lesions. The pad's surface was classified in four grades, according to the amount of surface covered with sulci, which were summed up for all four feet to a Pad Score (Ertl et al. 2019, Wendler et al. 2019).

Statistical analysis

Statistical analyses were carried out with R software Version 3.4.4. The information was only included in the analyses if there was no change

within the last year before examination. For each zoological institution, the mean number of each pathological lesion and care issue per elephant was calculated as well as the mean ParSev Score. Correlations with dichotomous variables were initially tested using Wilcoxon rank sum test with continuity correction and, in case of significant ($p < 0.05$) or nearly significant ($p < 0.10$) results, the point-biserial correlation coefficient was calculated. For ordinal variables, Kruskal-Wallis rank sum test and Spearman rank correlation coefficient were used similarly. Multiple comparisons were performed using Dunn's test with Holm p-value adjustment. The pathological findings and care issues were only included in the correlation calculations if they occurred in at least 10 institutions.

Table 2. Necessity of foot care in different locations of the feet of Asian elephants (*Elephas maximus*) evaluated in the video footage illustrated by sample images











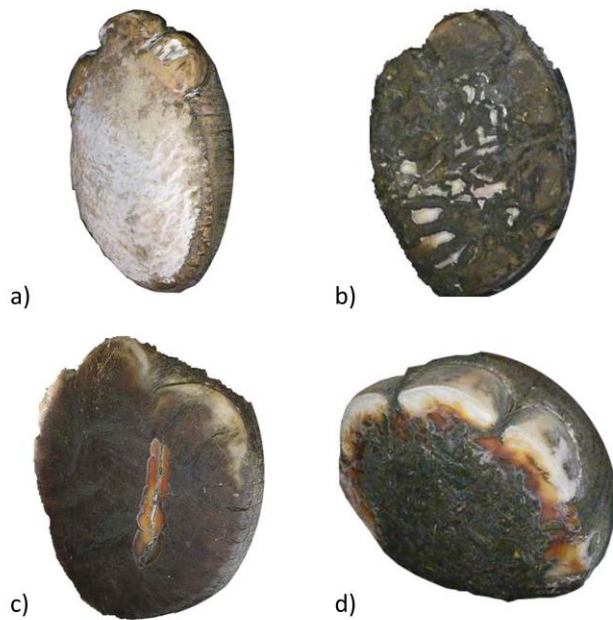
Location	Intervention necessary	Intervention not necessary
Cuticle	Frayed or attached to the nail 	Smooth 
Interdigital space	Less than one finger wide 	At least one finger wide 
Nail length	Longer than the pad → touch the ground when standing 	Shorter than the pad → do not reach the ground when standing 
Nail surface	Misshaped or rough 	Well shaped and smooth 
Nail defects	Present and not cut out 	Not present or cut out completely 

Table 3. Completeness of the pedicure treatment of different locations in Asian elephants (*Elephas maximus*)

Location	Treatment complete	Treatment incomplete	Not treated
Cuticle	Care taking in full length	Care taking only in parts	Not attended
Interdigital space	Widened to at least one finger width	Widened, but still less than one finger wide	Not widened
Nail length	Shortened, so that the nail is further away from the ground than the pad	Shortened, but the nail is still not further away from the ground than the pad	Not shortened
Nail surface	Nail trimmed to normal shape and surface smoothed	Surface attended, but nail not in normal shape and/or surface not smooth	Not attended
Nail defects	Necrotic tissue cut out completely	Necrotic tissue cut out incompletely	Not attended

**Figure 1.** Example pictures for different methods of pad trimming in Asian elephants (*Elephas maximus*): a) completely trimmed, b) partly trimmed, c) only sulci trimmed, d) not trimmed

Results

Results from interviews and correlations to ParSev Score

Of 243 elephants, 33.7% were kept in direct contact, whereas 66.3% were trained in protected contact. Although the point-biserial correlation between contact and ParSev Score was barely not significant ($r = -0.13$, $p = 0.056$), elephants treated in protected contact tended towards lower ParSev Scores than elephants in direct contact. A significant correlation could be found between contact and cooperativity of the elephants during foot care ($r = -0.20$, $p = 0.002$), which means that

elephants in direct contact were considered by the keepers as being more cooperative.

The majority of zoos (53 of 66 with no change within the last year) performed a reactive, non-regular pedicure, which means foot care was only performed if pathological lesions were noted. A prophylactic regular pedicure concept, i.e. performing a complete foot care irrespective of whether or not pathological lesions occur, was applied by 11 zoos. In two institutions, no foot care was performed (Fig. 2). Concerning these different approaches to foot care, no significant impact on the mean ParSev Score could be found ($p = 0.214$).

About a third of the institutions (34.8%) cared for their elephants' feet every two to three months. Half of the institutions (48.5%) performed their foot care at shorter intervals, and 16.6% at longer intervals (Fig. 3). Spearman rank correlation revealed that the frequency of foot care was significantly, negatively correlated with the mean ParSev Score ($r = -0.34$, $p = 0.009$), indicating less, or less severe, pathological lesions of feet with a higher frequency of foot care (Fig. 4). For particular pathological lesions and care issues, Kruskal-Wallis rank sum test did not reveal a significant result.

Whereas 41.8% of the zoos did not record their elephants' foot status, 35.8% took written and 22.4% photographic records (Fig. 5). None of the zoos used video recordings. Using Dunn's test for multiple comparisons, there was no significant impact of the recording method on the mean ParSev Scores per institution.

Three quarters of the keepers could name all four of the principle steps (attending cuticles, nails, interdigital spaces and pads) of a routine foot care, 15.2% mentioned three of four, 7.6% two steps, and 1.5% of the teams named only one step, but

Figure 2. Distribution of the concept of foot care in Asian elephants (*Elephas maximus*) in European (EAZA) institutions (n = 66)

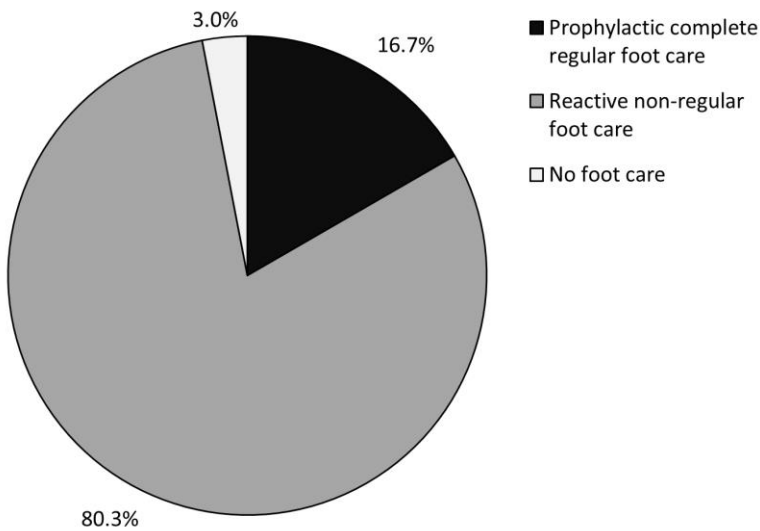


Figure 3. Distribution of the frequency of foot care in Asian elephants (*Elephas maximus*) in European (EAZA) institutions (n = 66)

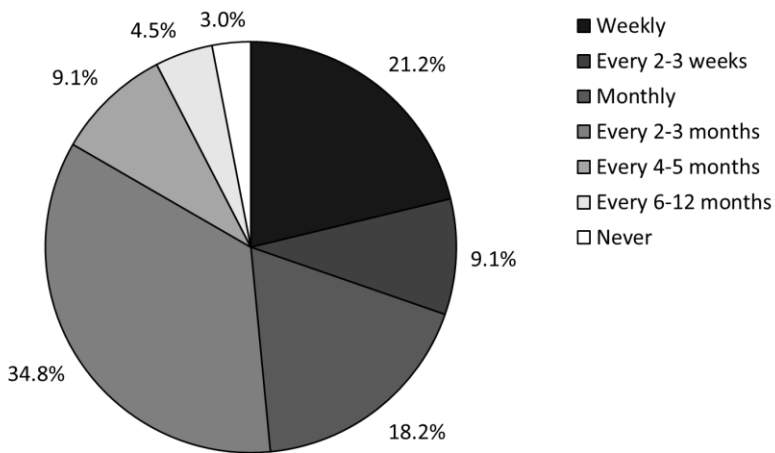


Figure 4. Mean ParSev Scores in relation to the frequency of foot care in Asian elephants (*Elephas maximus*) in European (EAZA) institutions (n = 59)

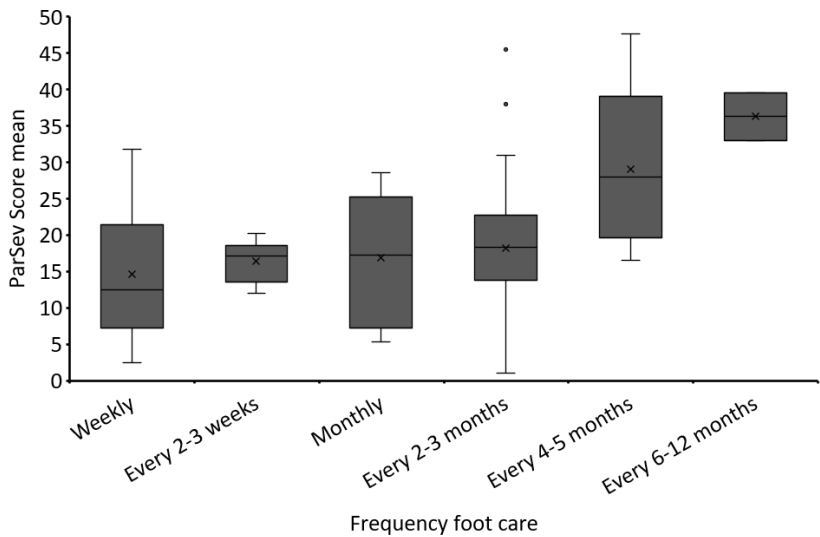


Figure 5. Distribution of record taking of foot care in Asian elephants (*Elephas maximus*) in European (EAZA) institutions (n = 67)

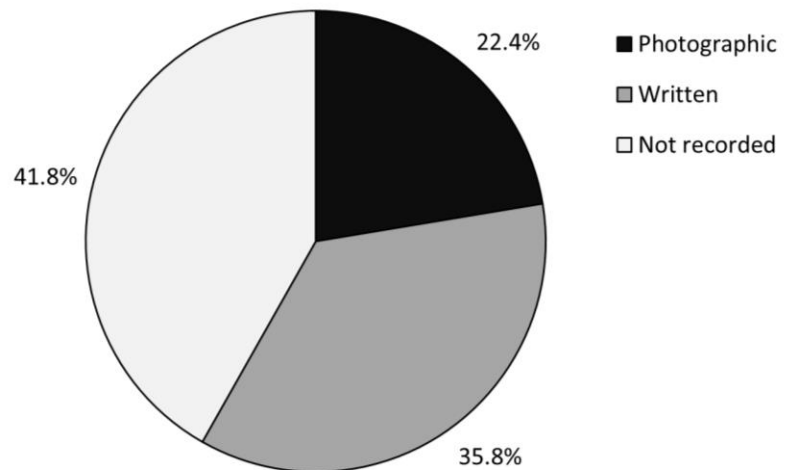
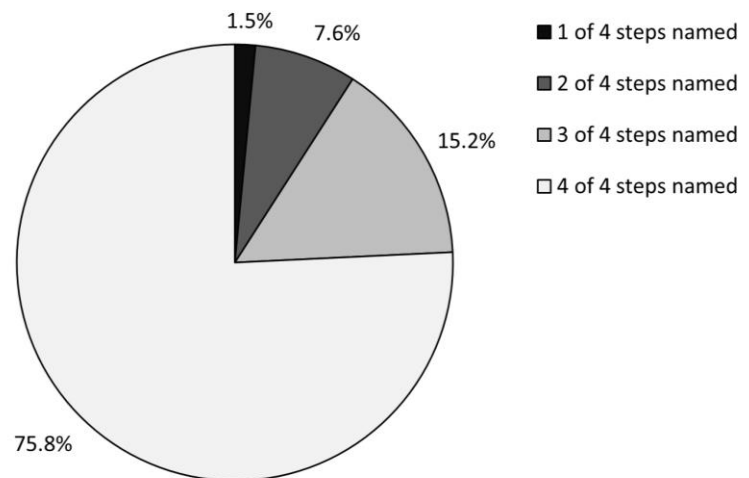


Figure 6. Distribution of the theoretical knowledge of elephant foot care among elephant keepers in European (EAZA) institutions (n = 66)



at least one step was named by every team (Fig. 6). No significant correlation was found between the theoretical knowledge of the keepers and the mean ParSev Score.

Results from videos

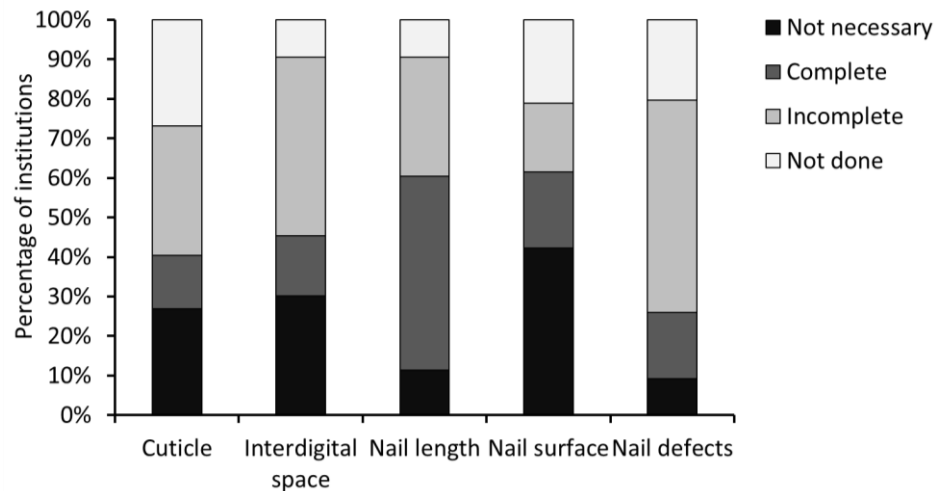
Video footage of the pedicure approach could be sampled from 54 institutions. In these videos, foot care in the five distinct locations (cuticles, nail surface, nail sole, interdigital space, pad) was necessary in 57.7% to 90.7% of the recorded feet. The lowest necessity was found on the nail surface, followed by the interdigital space (69.8%), the cuticle (73.1%), the nail length (88.7%) and it was highest for nail defects. From the cases with necessity for foot care, 29.4% were treated completely, 46.6% incompletely and 24.0% were not treated. Highest rates of a complete treatment were found for the nail length (55.3%) followed by

the nail surface (33.3%). The highest rates of an incomplete treatment were found for the interdigital space (64.9%) and nail defects (59.2%). The most-often not-attended locations were cuticles (36.8%) and the nail surface (36.7%) (Fig. 7).

The different treatment methods of the pad were evenly distributed (n = 49): 32.7% of the zoos trimmed the pad on the complete surface, 24.5% trimmed only a part of the pad surface, 16.3% solely cut out sulci and holes and 26.5% did not trim the pad at all. Using Kruskal-Wallis rank sum test, the different pad trimming methods were neither linked to significant differences in the mean ParSev Scores ($\chi^2 = 0.806$, df = 3, p = 0.848) nor did they reveal a significant impact on the mean Pad scores ($\chi^2 = 0.736$, df = 3, p = 0.865).

The most frequently used tools were hoof knives (highest percentage for treatment of

Figure 7. Necessity of foot care and completeness of treatment in Asian elephants (*Elephas maximus*) ($n_{\text{Cuticle}} = 52$, $n_{\text{InterdigitalSpace}} = 53$, $n_{\text{NailLength}} = 53$, $n_{\text{NailSurface}} = 52$, $n_{\text{NailDefects}} = 54$)



cuticles, nail defects and pad) and rasp (highest percentage for treatment of interdigital space, nail length and nail surface). As an electric device, the angle grinder had second highest percentage for treatment of cuticles, nail length and nail surface (Table 4). Using point-biserial correlation, the usage of an angle grinder came along with a significantly higher mean ParSev Score ($r = 0.28$, $p = 0.031$) as well as a significantly higher occurrence of solar horn defects ($r = 0.26$, $p =$

0.049) and interdigital spaces narrower than one finger width ($r = 0.32$, $p = 0.015$). These relations are also evident when plotting the distribution of the mean ParSev Scores (Fig. 8) and the solar horn defects per elephant (Fig. 9) in relation to the use of an angle grinder. The elephants of twice as many institutions were affected by too narrow interdigital spaces when their foot care was performed using an angle grinder compared to manual treatment using hoof knives and rasps

Table 4. Absolute and relative frequencies of tool usage in European institutions for each location in the feet of Asian elephants (*Elephas maximus*) (drawings by Mandy Ziegler)







Location	Hoof knife	Swiss hoof knife	Rasp	Pliers	Angle grinder	Dremel
						
Cuticle	15 45.5%	1 3.0%	6 18.2%	3 9.1%	7 21.2%	1 3.0%
Interdigital space	23 39.7%	3 5.2%	24 41.4%	0 0%	8 13.8%	0 0%
Nail length	14 18.7%	8 10.7%	32 42.7%	1 1.3%	20 26.7%	0 0%
Nail surface	0 0%	0 0%	15 53.6%	0 0%	13 46.4%	0 0%
Nail defects	27 51.9%	5 9.6%	11 21.2%	0 0%	8 15.4%	1 1.9%
Pad	21 44.7%	17 36.2%	2 4.3%	0 0%	7 14.9%	0 0%
All combined	100 34.1%	34 11.6%	90 30.7%	4 1.4%	63 21.5%	2 0.7%

Figure 8. Mean ParSev Score in relation to angle grinder usage during foot care in Asian elephants (*Elephas maximus*) ($n_{\text{NoGrinder}} = 33$, $n_{\text{Grinder}} = 26$)

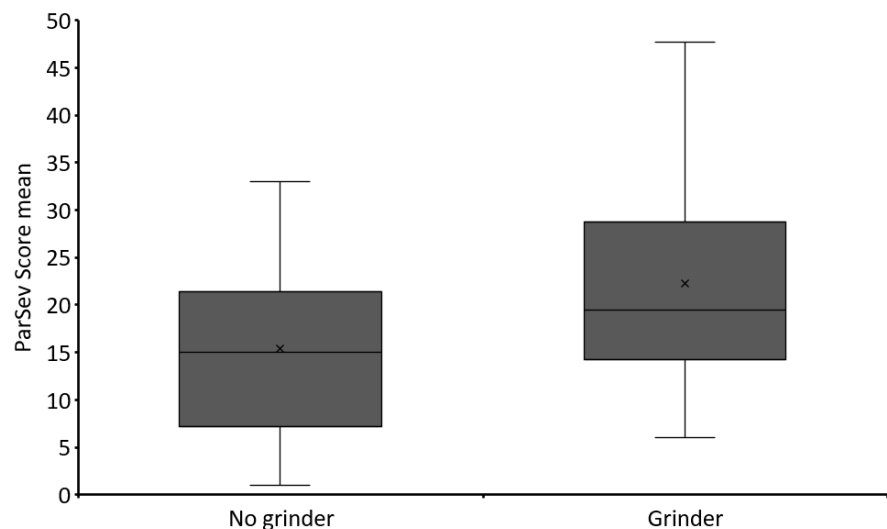
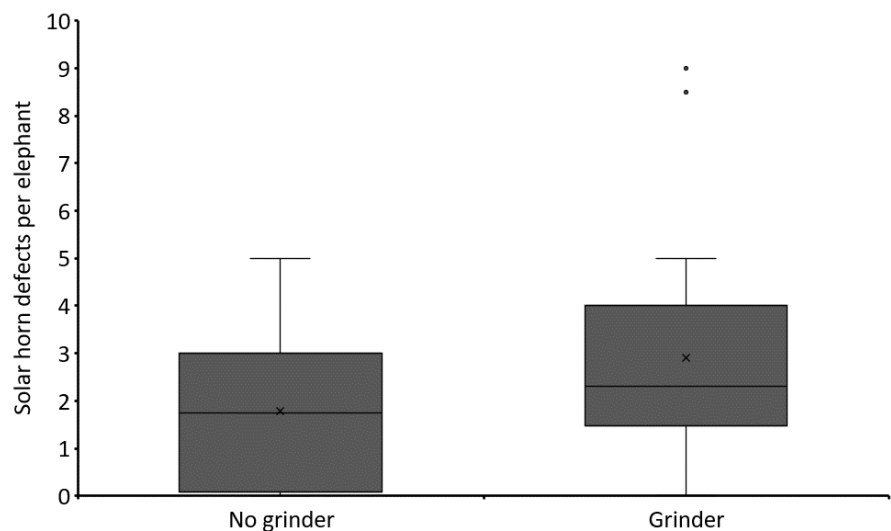


Figure 9. Solar horn defects per elephant in relation to angle grinder usage during foot care in Asian elephants (*Elephas maximus*) ($n_{\text{NoGrinder}} = 33$, $n_{\text{Grinder}} = 26$)



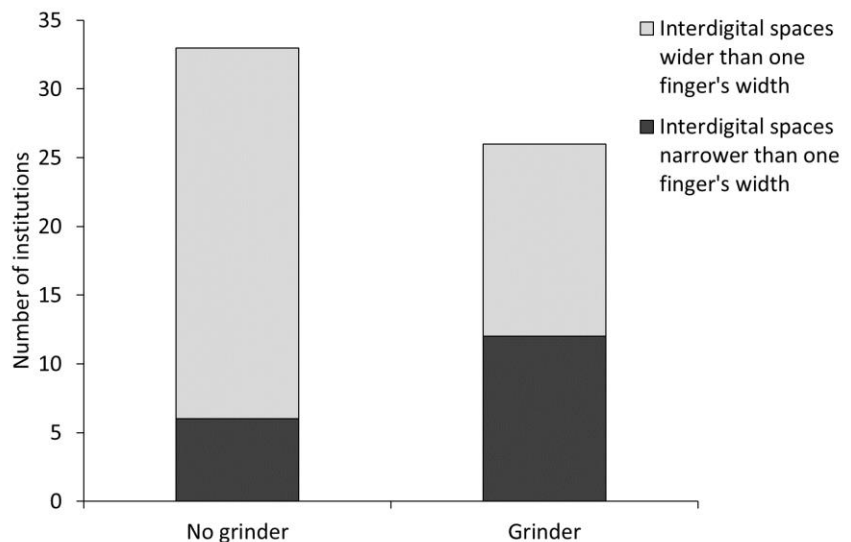
(Fig. 10). No significant difference was found for the frequency of foot care depending on the grinder usage via Wilcoxon rank sum test ($W = 630.5$, $p = 0.090$), indicating that institutions using an angle grinder did not perform foot care more frequently (Table 5).

Discussion

Foot care in Asian elephants is implemented in the management schedule of 97% of the considered institutions and is an important topic of elephant husbandry. Investigating individual data of 243 elephants and video footage of 54 institutions, this study gives an overview of various aspects of the routine foot care approach in Asian elephants. Although acquiring information was sometimes affected by language barriers, data acquisition of information and photographs of the individual

elephants followed a standardised protocol to provide comparable data. The evaluation of the video footage must be viewed with caution, since only one foot care procedure was recorded per institution, in order to characterise the foot care procedure for each zoo. It is probable that the approach varied from the usually performed one, either due to the desire to present a more complete procedure than usually performed, or because of demonstrating a reduced approach due to time limitations caused by our data collection. Another aspect is that only the approach of one elephant keeper on one elephant was recorded, which might not be sufficiently representative for the approach of the other keepers, or on the other elephants, in the same institution. Nevertheless, this analysis serves for the presentation of the principle aspects of foot care in captive Asian

Figure 10. Distribution of the care conditions of interdigital spaces in the feet of captive Asian elephants (*Elephas maximus*) depending on the usage of an angle grinder during foot care



elephants and reveals several noteworthy correlations.

Contact

One third of the evaluated elephants were kept in direct contact. The remaining two thirds were worked with in protected contact, which means that a barrier separates the working spaces of elephants and keepers (Fowler 2006). Protected contact training is based on a positive reinforcement operant conditioning, where the elephant participates voluntarily and the trainers work without any punishment or negative reinforcement (Desmond and Laule 1991).

In some institutions, the whole herd was kept in protected contact, whereas in others the cows were treated in direct and only the bulls in protected contact. To perform proper foot care, different structural and training conditions are required depending on the actual contact type (Roocroft and Oosterhuis 2001). In direct contact, the elephant is typically trained and controlled using an ankus. Foot care is usually performed by two trained keepers: one calls the elephant's attention, whereas the other one works on the feet. An elephant tub serves to position the elephant's foot properly (Hughes and Southard 2001). In protected contact, target training is used to teach the elephant to present its feet through an opening in the stall front of the protected area. As for the direct contact, two keepers are needed to position the elephant and perform the pedicure (Kalk and Wilgenkamp 2001). Schwammer (2001) described direct contact as being best for foot care, whereas Roocroft and Oosterhuis (2001) state that

depending on proper training, foot care can be performed successfully irrespective of the contact type.

Due to the interviews, keepers assessed elephants that were handled in direct contact as being more cooperative than the ones trained in protected contact. Nevertheless, no significant correlation was found between contact type and the ParSev Score, which implies that the feet can be cared for equally well in both systems. Given the prospect that protected contact will be the most common zoo elephant husbandry system in the future, this finding is reassuring.

Foot care schedule

To prevent the development of foot problems, prophylactic regular complete foot care procedures are recommended by Roocroft and Oosterhuis (2001). Nevertheless, this concept was only followed by 16.7% of the zoos. The majority of institutions (80.3%) carried out a reactive, non-regular foot care, where the feet are only trimmed when pathological lesions occur. This might be due to a deficient number of elephant keepers and a lack of time in their daily work schedules, which was reported by many teams, or by a general concept focussing on reactive rather than prophylactic care. As no significant difference in the mean ParSev Score values could be found, the general concept of the foot care does not seem to be influential on the general foot health. A reason for that could be generally improving husbandry conditions, and focussing on an enriched environment, where nails and pads wear naturally, so that a problem-based foot care suffices.

Table 5 Statistical analyses on correlations concerning foot care in Asian elephants (*Elephas maximus*)

Variable	Correlated with	Non-parametric statistical test	Correlation	Mean values	Median values
I) Multiple comparison with Dunn's test and Holm p-value adjustment					
Record	Mean ParSev Score	Not recorded to written: z = 0.964, p _{adj} = 1.000		20.17 (not rec.)	17.47 (not rec.)
		Photographic to not recorded: z = 0.024, p _{adj} = 0.981		18.11 (photogr.)	20.17 (photogr.)
		Written to photographic: z = -0.809, p _{adj} = 0.419		16.64 (written)	16.00 (written)
II) Wilcoxon rank sum test and point-biserial correlation for dichotomous variables					
Contact	ParSev Score	W = 5671, p = 0.056^	r = -0.13, p = 0.056^	21.74 (direct c.) 17.38 (protected c.)	18.00 (direct c.) 17.00 (protected c.)
	Cooperativity	W = 8069, p = 0.002*	r = -0.20, p = 0.002*	4.55 (direct c.) 4.08 (protected c.)	5.00 (direct c.) 4.00 (protected c.)
Grinder	Mean ParSev Score	W = 289, p = 0.033*	r = 0.281, p = 0.031*	22.30 (grinder) 15.41 (no grinder)	19.43 (grinder) 15.00 (no grinder)
	Minor nail cracks ^a	W = 326, p = 0.117			
	Attached cuticles ^a	W = 349, p = 0.226			
	Solar horn defects ^a	W = 301, p = 0.051^	r = 0.257, p = 0.049*	2.90 (grinder) 1.78 (no grinder)	2.30 (grinder) 1.75 (no grinder)
	Major nail cracks ^a	W = 362, p = 0.308			
	Altered tissues ^a	W = 361.5, p = 0.132			
	Frayed edges of pads ^b	W = 415, p = 0.810			
	Narrow interdigital spaces ^b	W = 301, p = 0.017*	r = 0.315, p = 0.015*	0.17 (grinder) 0.09 (no grinder)	0 (grinder) 0 (no grinder)
	Frayed cuticles ^b	W = 353, p = 0.248			
	Solar fissures ^b	W = 344.5, p = 0.199			
	Rough nail surface ^b	W = 462.5, p = 0.613			
	Frequency foot care	W = 630.5, p = 0.090	r = -0.213, p = 0.089	4.42 (grinder) 4.95 (no grinder)	4 (grinder) 5 (no grinder)
III) Kruskal-Wallis rank sum test and Spearman rank correlation for ordinal variables					
Concept	Mean ParSev Score	χ ² = 1.542, df = 1, p = 0.214			
Frequency	Mean ParSev Score	χ ² = 11.199, df = 5, p = 0.048*	r = -0.339, p = 0.009*		
	Minor nail cracks ^a	χ ² = 4.189, df = 5, p = 0.523			
	Attached cuticles ^a	χ ² = 5.286, df = 5, p = 0.382			
	Solar horn defects ^a	χ ² = 8.650, df = 5, p = 0.124			
	Major nail cracks ^a	χ ² = 9.711, df = 5, p = 0.084^	r = -0.082, p = 0.537		
	Altered tissues ^a	χ ² = 5.364, df = 5, p = 0.373			
	Frayed edges of pads ^b	χ ² = 3.984, df = 5, p = 0.552			

	Narrow interdigital spaces ^b	$\chi^2 = 3.196$, df = 5, p = 0.670
	Frayed cuticles ^b	$\chi^2 = 3.839$, df = 5, p = 0.573
	Solar fissures ^b	$\chi^2 = 7.557$, df = 5, p = 0.182
	Rough nail surface ^b	$\chi^2 = 2.205$, df = 5, p = 0.820
Theoretical approach	Mean ParSev Score	$\chi^2 = 0.493$, df = 2, p = 0.782
Pad trimming	Mean ParSev Score	$\chi^2 = 0.806$, df = 3, p = 0.848
	Pad Score	$\chi^2 = 0.736$, df = 3, p = 0.865

* p-value < 0.05, ^ p-value between 0.05 and 0.10, ^a pathological lesions and ^b care issues according to Wendler et al. (2019)

Roocroft and Oosterhuis (2001) propose 90 days as a sensible pedicure interval. From the different intervals that were stated in this study (Fig. 3), 'every 2-3 months' was most common with 34.8%. But weekly and monthly performed foot care were also named by roughly a fifth of the institutions each. The correlation of the mean ParSev Score to the frequency reveals a better general foot health when the feet are cared for more frequently. So, to maintain the elephants' feet in a good health condition, it appears to be more important to attend to them more frequently than to always do a complete foot care. Irrespective of foot care procedures, feet should be inspected daily to ensure early detection of problems and timely reaction (Fowler 2001, Schwammer 2001, West 2001).

To keep track of the foot care schedule especially in case of prolonged healing processes, taking records can be very helpful. They can be carried out in written form, e.g. using a computerised database, photographically or by videotapes (Rutkowski et al. 2001a). More than half of the included zoos used records either in written or photographic form, but this had no influence on the ParSev Score.

An effective foot care can only be achieved if the staff possesses the specific knowledge and skills (Roocroft and Oosterhuis 2001). Targets for the pedicure are cuticles, nails, interdigital spaces and pads (Kock 1994, Roocroft and Oosterhuis 2001). Most of the teams could name them entirely, indicating strong basic theoretical knowledge. The opportunity to acquire specific foot care knowledge by participating in workshops, having a consultant, or visiting other teams was given to 43 of 69 elephant teams. The remaining teams transferred the knowledge from experienced to the following keepers within the institutions. Reason for the non-significance of the correlation between theoretical knowledge and the mean ParSev Score could be the strongly declining distribution, with 75.6% naming four of four steps. This result might also mean that improving the theoretical knowledge of elephant staff is a less promising approach towards better foot health than the instigation of other measures, such as installing regular, high-frequency foot care procedures as part of the general husbandry concept. So, rather than only focussing on theoretically educating staff, staff should be given more time to apply their knowledge.

Foot care approach in videos

After the evaluation of the theoretical knowledge, the analysis of the videos allowed an evaluation of the actual practical skills. Roocroft and Oosterhuis (2001) and Kock (1994) describe necessary steps of a pedicure. To prevent overgrowth, fraying and the development of fluid pockets, cuticles need to be trimmed. Nails should be shortened, and the edge rasped to a rounded shape. The interdigital space should be rasped to one finger's width and existing defects like cracks or abscesses need to be treated by removing necrotic material.

The high necessity of foot care in the present study, with 76.0% on average at the beginning of a documented pedicure session, must not be interpreted as a bad condition, since the keepers were asked to present their approach on a foot that was 'in turn'. But only 22.7% of the necessary areas were treated completely. In some cases, an incomplete treatment might be part of the training routine, because some elephants might be more cooperative in the long term if training is rather short and positive, instead of long and with declining interest of the elephant. This is particularly applied when the elephant is not used to the approach yet, or when foot care might be associated with pain, for example when treating nail defects, or due to arthrosis. As compensation for shorter and incomplete treatments, they should be applied more frequently. Testing the correlation between the completeness of treatment and the frequency revealed that the more areas were treated incompletely in our sample, the higher was the reported frequency of foot care ($r = 0.43$, $p = 0.002$), clearly indicating this strategy. In pain-free and well-trained elephants, prophylactic foot care should nevertheless be complete as this helps preventing foot problems (Roocroft and Oosterhuis 2001). Neither lack of time nor lack of experience should be a reason for an incomplete treatment. In addition to teaching theoretical concepts to the keepers, good instruction and practical exercises under supervision through workshops, consultants or more experienced colleagues are essential to increase the practical skills and knowledge about a complete procedure.

Different states of, and approaches to caring for, the pads were found. Some pad surfaces were completely smooth, others with a thick horn layer crisscrossed by deep sulci. Some were

completely trimmed, others partly or only the sulci were cut out and some were not trimmed at all. With sufficient strain like walking on different substrates, digging or processing branches, the pads should theoretically wear down naturally. In case of a lack of these activities in captivity, pad trimming might be necessary, but should always be done carefully, leaving enough horn tissue (Kock 1994, Roocroft and Oosterhuis 2001). Since no significance to the mean ParSev Score could be found, it can be suggested that the pad trimming method has no influence on the general foot health. Unexpectedly, there was also no significant correlation to the mean pad score. This suggests that other factors such as substrate or activity are more influential on the pad's structure than the trimming method.

Tools

Basic tools used for pedicure in elephants are hoof knives and hoof rasps (Roocroft and Oosterhuis 2001), which can be individually supplemented by special equipment like hoof groovers, Swiss hoof knives and hoof nippers (Fowler 2001). This corresponds to the results of our study: the most frequently used tools were hoof knives and rasps, but also Swiss hoof knives, pliers and Dremel rotary tools were applied.

There are controversial opinions on the use of power tools, like sanders, planers or angle grinders. On the one hand, they make the foot work less strenuous and quicker, which may allow implementing foot care at a higher frequency (Hughes and Southard 2001). On the other hand, they increase the risk for injuries, since they remove foot tissue rapidly and the generated heat inhibits bleeding, so that it is more difficult to notice when to stop trimming. Additionally, power tools generate noise and vibrations, which could distract the elephants if not trained well enough (Roocroft and Oosterhuis 2001).

An angle grinder was applied in 41% of institutions, and it was used to process all parts of the nail and the pad. A positive correlation was found between the usage of an angle grinder and the mean ParSev Score, which means that the general foot health was better in zoos that did not use a grinder. Reason for this correlation could be the previously mentioned injuries due to the high speed of these tools. Besides, no significantly higher frequency of foot care could be found for the institutions using an angle

grinder. Actually, comparing mean values of the frequencies, manually proceeding facilities tended ($p = 0.089$) to perform foot care more frequently than the ones using power tools. Analysing the prevalence of the pathological lesions depending on the grinder usage, a higher occurrence of solar horn defects was found in zoos where the grinder was used. These solar horn defect could be a development of smaller injuries. Additionally, significantly more interdigital spaces were too narrow, which implies that the grinder is not the preferable tool for this part of the foot and that hoof knives and rasps are more suitable. Although there was no significant correlation, we particularly advise against using the electric grinder for cuticle trimming, since this is soft and very sensitive tissue, which can easily be damaged causing pain for the elephant. Pliers and hoof knives are more suitable tools for cuticle work.

Yet, no matter which tools are used, it is important to create adequate circumstances to perform an effective foot care. Tools must be clean and sharp (Fowler 2001, Roocroft and Oosterhuis 2001, Schwammer 2001). Hones might be used for sharpening, but with regard to work facilitation and time saving, the one-off purchase of an electric knife sharpener should be considered. Additionally, it is important to have good light conditions during the pedicure. Since especially in the central and northern European countries, foot care is usually performed indoors, and the training areas often do not have sufficient natural light, the usage of an additional spotlight is advisable. Furthermore, the position should be comfortable for both, elephants and keepers, as the complete care of one foot takes about one hour (Roocroft and Oosterhuis 2001). The height, on which the elephant needs to position its feet, should be adjustable for front and hind legs and the individual body heights. Knee pads may support the keepers in uncomfortable positions. Alternatively, the training area could be designed so that the elephant stands higher than the keeper, which helps relieve back strain for the latter. These additional recommendations result from the observations and experiences gained in the course of this study but have not been part of the general data collection or analysis.

Conclusion

The majority of zoos used foot care to improve the elephants' foot health condition. The approaches varied between the institutions especially concerning contact type, frequency, record-taking and equipment. Correlations with pathological foot lesions revealed that applying foot care in a high frequency and using manual tools like hoof knives and rasps instead of angle grinders are beneficial for the foot health. Basic prerequisites for performing an adequate pedicure are well-trained elephants and theoretically and practically skilled staff with sufficient time.

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**Body condition scores of European zoo elephants
(*Elephas maximus* and *Loxodonta africana*):
Status quo and influencing factors**

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Research article

Body condition scores of European zoo elephants (*Elephas maximus* and *Loxodonta africana*): Status quo and influencing factors

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Abstract

Obesity is a common problem in captive elephants. Therefore, physical state monitoring presents a critical aspect in preventive elephant healthcare. Some institutions lack the equipment to weigh elephants regularly, so body condition scoring (BCS) is a valuable alternative tool. As yet, the BCS of both elephant species has not been assessed comprehensively for the European captive population. Using a previously validated visual BCS protocol, we assessed 192 African (*Loxodonta africana*) and 326 Asian elephants (*Elephas maximus*) living in European zoos (97% of the living European elephant population). The majority of elephants scored in the upper categories with 56% of adults assessed in the range 7–10 out of 10. Adult Asian elephants had significantly lower BCS (males: mean 6.2 ± 1.0 , median 6.0, range 4–8; females: mean 6.6 ± 1.3 , median 6.0, range 3–9) than African elephants (males: mean 6.7 ± 0.7 , median 6.0, range 6–8; females: mean 6.9 ± 1.2 , median 6.0, range 1–9). Comparison with samples of free-ranging populations (163 Asian elephants and 121 African elephants) revealed significantly lower scores in free-ranging elephants independent of species, age and sex category. Compared to previous reports from captive populations, the European zoo elephant population is nevertheless less obese. In adult Asian elephant females, BCS was significantly correlated to their breeding status with lower scores in current breeders; however, breeding status was also correlated to group size, enclosure size, and a diet with less vegetables. Further attention to zoo elephant weight management is recommended with regular longitudinal monitoring by body condition scoring.

Introduction

Because of their body size, intelligence, importance to the public and conservation status, captive management of African (*Loxodonta africana*) and Asian elephants (*Elephas maximus*) is challenging. Optimising nutritional intake for elephants in captivity can be problematic, and several reports have highlighted the problems of feeding regimes and found obesity to be common (Harris et al. 2008; Hatt and Clauss 2006; Morfeld et al. 2016). Weight management is therefore an important focus for good elephant husbandry, and body weight monitoring an important part of preventative medicine. However, the sheer size and expense of the required technical

equipment means regular weight monitoring might not be feasible for many elephant-keeping zoos. Visual body condition scoring (BCS) is considered a useful method to reliably assess zoo animals including elephants (reviewed in Schiffmann et al. 2017), although none of these have defined an ideal score range with regards to health.

Several indices have recently been developed for elephants and applied in free-ranging as well as semi-captive and captive populations (Fernando et al. 2009; Morfeld et al. 2014; Morfeld et al. 2016; Treiber et al. 2012; Wemmer et al. 2006; Wijeyamohan et al. 2015). Scores are affected by age (Chusyd et al. 2018; Somgird et al. 2016b), sex (Godagama et al. 1998; Morfeld et al. 2016; Pinter-Wollman et al. 2009; Ramesh et

al. 2011), living conditions (Morfeld et al. 2014; Wijeyamohan et al. 2015), season (Albl 1971; De Klerk 2009; Foley et al. 2001; Pinter-Wollman et al. 2009; Pokharel et al. 2017; Ramesh et al. 2011; Ranjeewa et al. 2018), husbandry parameters (Harris et al. 2008; Morfeld et al. 2016), reproductive status such as lactation (De Klerk 2009), faecal glucocorticoid metabolites (Pokharel et al. 2017), history of translocation (Pinter-Wollman et al. 2009) and duration of musth (Poole 1989; Somgird et al. 2016b). More extended information on previous research on elephant body condition scoring is compiled in Supplement 1 (Table S1 and S2).

In general, values in the middle range of an index are considered ideal with reference to the protocols in pets and farm animals (Santarossa et al. 2017). Based on these assumptions, a high percentage of zoo elephants in the UK and North America have been evaluated as overweight or obese (Harris et al. 2008; Morfeld et al. 2016). Morfeld et al. (2016) conducted an extensive review of the North American zoo elephant population (240 elephants in 65 institutions). However, apart from Harris' (2008) welfare evaluation of the entire UK zoo elephant population (n=70), no study has applied a BCS index to a substantial sample size in European captive elephants, which consists of about 500 individuals (Schwammer and Fruehwirth 2015; van Wees and Damen 2016). The aim of the present study was to establish a population-wide overview of elephant body condition in these 500 animals and to perform a comparison to two free-ranging populations.

Material and methods

In January 2016, 189 African and 294 Asian elephants were included in the European endangered species program (EEP) studbooks for the European zoo elephant population. The studbook for the Asian species provides a list of 51 elephants that do not participate in the EEP. A corresponding list does not exist for the African elephant, although several individuals not recorded in the EEP are known to live in European zoos, resulting in a total of 534 individual elephants considered in our study.

Life history and husbandry data collection

Basic life history data of the individual elephants were taken from the current compilations in the EEP-studbooks at the end of March 2017 with subsequent data analysis until November 2017. Additionally, information concerning management system, enclosure sizes, diet composition, feeding regime, weight documentation and reproductive status were collected by interviewing staff members (veterinarians, curators and keepers) during visits on site or by questionnaire via mail or phone.

Body condition scoring

We used one standardised photograph showing the elephant in side profile as basis for the scoring, as for other recent scoring protocols (Fernando et al. 2009; Morfeld et al. 2014; Morfeld et al. 2016; Wijeyamohan et al. 2015). Pictures of European zoo elephants were taken while visiting facilities on site, and facilities

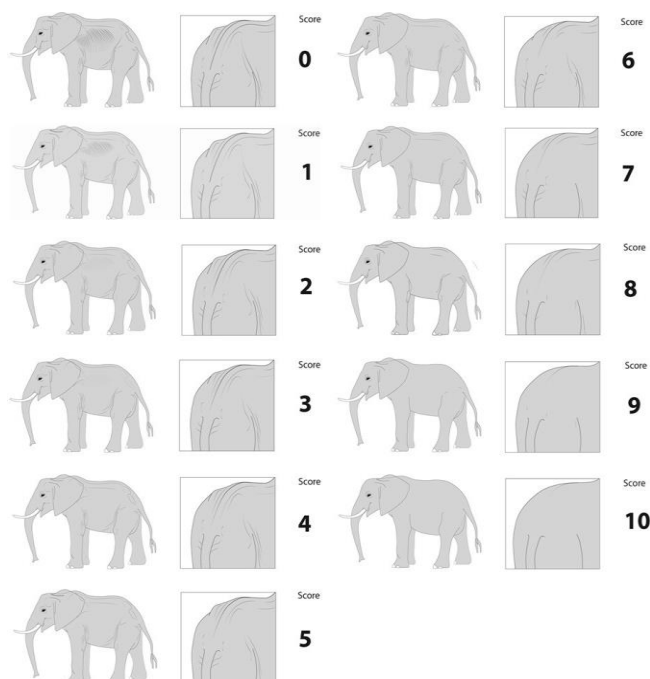


Figure 1. Example drawings used for body condition scoring of African elephants (*Loxodonta africana*) (drawings by Jeanne Peter)

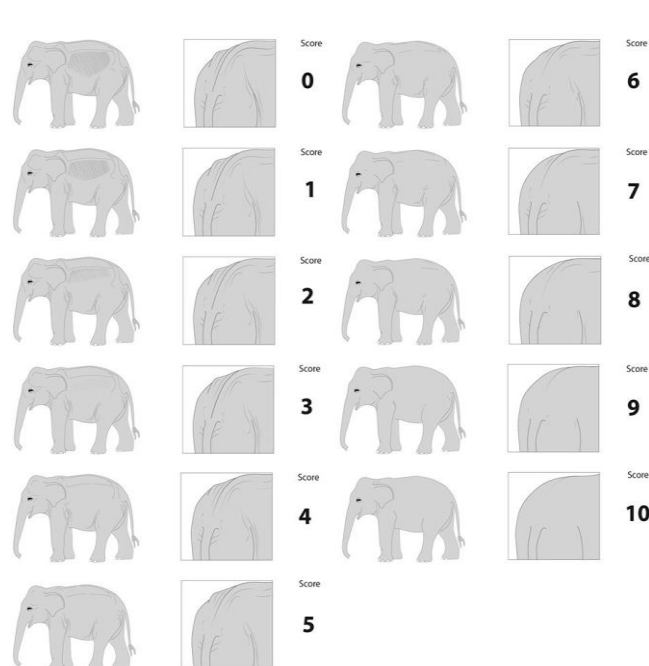


Figure 2. Example drawings used for body condition scoring of Asian elephants (*Elephas maximus*) (drawings by Jeanne Peter)

in which a personal visit was not feasible were contacted by mail or phone and asked to provide current photographs of their individual elephants. To be included in the study, a pictorial document had to fulfill the following criteria: i) datable to a month (where an accurate date was missing, the 1st day of the month was recorded); ii) clearly identifiable individual; iii) sufficient recognition of the relevant body regions (backbone, pelvic bone, ribs, skin fold on the base of the tail); iv) standing or moderate walking body position to allow reliable assessment; and v) adequate resolution of the photograph, based on recognition of the generic wrinkles on the skin surface of the elephant, absence of distinct patterns of shade or large amounts of hay, straw or other substrates on the back of the elephant.

To assign a consistent BCS to every photograph we combined species-specific indices in an overview following Schiffmann et al. (2017) (for African elephants from Morfeld et al. 2014; for Asian elephants from Fernando et al. 2009, Wijeyamohan et al. 2015 and Morfeld et al. 2016). Recent work has suggested scoring may reach a higher reproducibility and repeatability by using example drawings as opposed to pictures (Vieira et al. 2015). Therefore, we had exemplar drawings made for every score and each species that showed elephants in side profile and from behind (Figures 1 and 2). The focus was laid on the visibility of indicated bone structures of the lumbar region, which have been shown to correlate best with the amount of body fat in elephants (Albl 1971; Morfeld et al. 2014; Morfeld et al. 2016). In addition, the overall appearance of the elephant was taken into account and was considered more

important than single characteristics (e.g. visibility of ribs or edges of the scapula), following the findings of Schiffmann et al. (2017). Elephant pictures were scored independently of age and sex by the first author, using the technical size of the picture to generate a random order to reduce observer bias. To check the method for intra-examiner agreement, a random sample (n=500) of pictures was evaluated twice and scores compared.

Collection of pictorial samples from free-ranging populations

We collected a sample of photographs from both species from the wild. For the Asian elephant, 163 photographs of the Yala National Park (Sri Lanka; 6° 16' N, 81° 20' E) population taken randomly between 2006 and 2014 were scored. The individually pictured elephants were grouped into the following age and sex categories: calves (<5 years), juveniles (5–15 years), adult females (>15 years) and adult males (>15 years). We defined the applied categories on various age class systems for both elephant species (Arivazhagan and Sukumar 2008; Moss 2001; Pokharel et al. 2017). This sample consisted of 51 calves, 32 juveniles, 50 adult females and 30 adult males. For the African species, 121 photographs of the Amboseli National Park (Kenya; 2° 38' S, 37° 14' E) population taken randomly between 2001 and 2016 were scored. This sample consisted of 29 calves, 28 juveniles, 40 adult females and 27 adult males. Both samples were balanced regarding age and sex category. We were unable to assess season for either free-ranging population, although seasonal changes in body condition do occur (De Klerk 2009; Foley et al. 2001; Ramesh et al. 2011; Ranjeewa et al. 2018).

Table 1. Body condition scores of the African elephant (*Loxodonta africana*) population in European zoos and a sample of their free-ranging counterparts in Amboseli National Park, Kenya

Age/sex category	N	Score range	Average \pm SD	Median	First quartile	Third quartile
Calves (<5 years)**						
Zoo	12	6–8	7.15 \pm 0.69	7.00	7.00	8.00
free-ranging	29	5–8	6.39 \pm 0.79	6.00	6.00	7.00
Juveniles (5–15 years)**						
Zoo	48	5–8	6.45 \pm 0.71	6.00	6.00	7.00
free-ranging	28	5–8	5.89 \pm 0.74	6.00	5.00	6.00
Adult females (>15 years)***						
Zoo	108	1–9	6.90 \pm 1.19	7.00	6.00	8.00
free-ranging	40	5–8	6.03 \pm 0.85	6.00	5.00	6.75
Adult males (>15 years)(*)						
Zoo	21	6–8	6.67 \pm 0.75	7.00	6.00	7.00
free-ranging	27	5–8	6.33 \pm 0.83	6.00	6.00	7.00

Significant difference (U-test): *** P<0.001, ** P<0.01, * P<0.05; (*): P=0.054

Table 2. Body condition scores of the Asian elephant (*Elephas maximus*) population in European zoos and a sample of their free-ranging counterparts in Yala National Park, Sri Lanka

Age/sex category	N	Score range	Average \pm SD	Median	First quartile	Third quartile
Calves (<5 years)***						
Zoo	49	4–9	6.59 \pm 0.98	7.00	6.00	7.00
free-ranging	51	3–7	5.39 \pm 0.92	5.00	5.00	6.00
Juveniles (5–15 years)***						
Zoo	69	5–9	6.72 \pm 1.16	7.00	6.00	7.00
free-ranging	32	3–7	5.25 \pm 0.89	5.00	4.75	6.00
Adult females (>15 years)***						
Zoo	179	3–9	6.58 \pm 1.29	7.00	6.00	7.00
free-ranging	50	3–7	5.30 \pm 1.02	5.00	5.00	6.00
Adult males (>15 years)*						
Zoo	29	4–8	6.21 \pm 0.98	6.00	6.00	7.00
free-ranging	30	2–7	5.53 \pm 1.04	6.00	5.00	6.00

Significant difference (U-test): *** P<0.001, ** P<0.01, * P<0.05

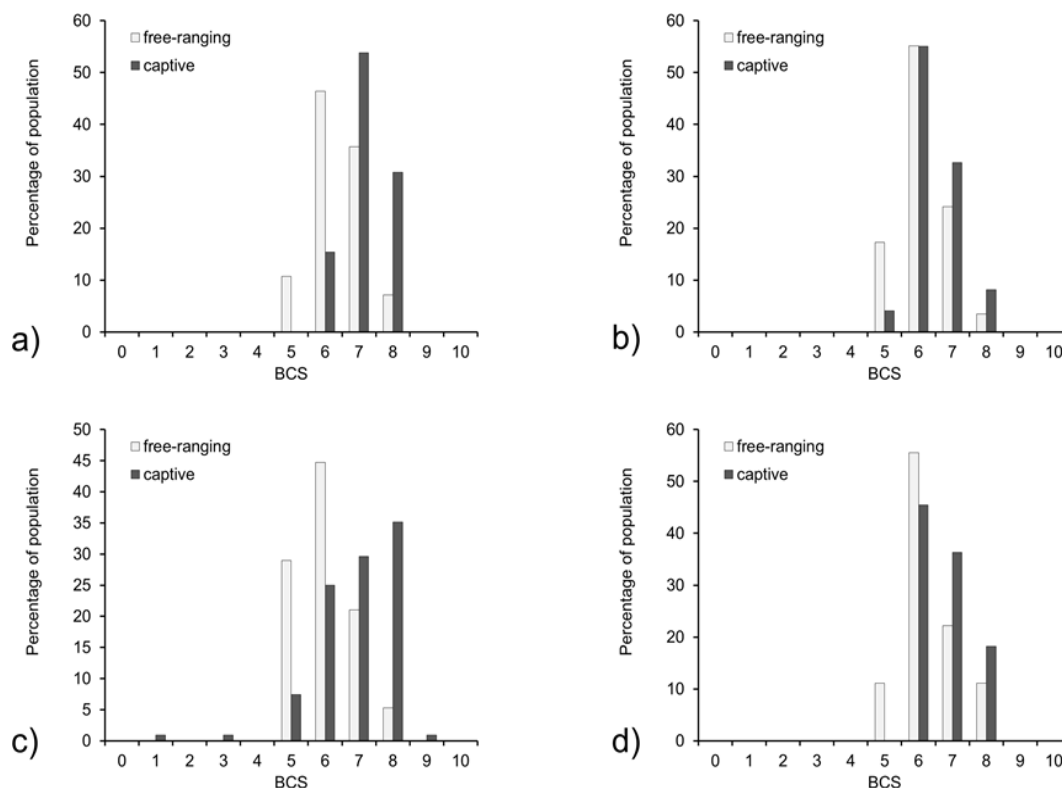


Figure 3. Distribution of body condition scores in populations of free-ranging (n=121) and captive (n=189) African elephants (*Loxodonta africana*). a) Calves (<5 years), b) Juveniles (5–15 years), c) Adult females (>15 years), d) Adult males (>15 years)

Comparison with literature data

Due to the differences in the BCS systems used in the literature, absolute scores were not directly comparable: for example, in a system with a score range of 1–5, a BCS of 5 indicates obesity, whereas it would indicate an intermediate state in a system with a score range from 1–10. In order to put our results into a comparative perspective, we compared our data (BCS range 0–10) to the data of Morfeld et al. (2016) (BCS range 1–5), equating our scores of 9–10 to their score of 5, our scores of 7–8 to their score of 4, etc. Additionally, we calculated a standardised score by expressing the mean or median score reported in publications as a proportion of the total score range, adjusting the range so that higher values indicate obesity. Thus, for example, a standardised score of 0.8 would indicate that the mean/median score was in the last (upper) quartile of the score range.

Statistical analysis

Body condition scores are non-parametric data by definition, and therefore, data should be represented by medians and quartiles; however, following recent convention (Chusyd et al. 2018; De Klerk 2009; Foley et al. 2001; Godagama et al. 1998; Harris et al. 2008; Kumar et al. 2014; Morfeld and Brown 2016; Morfeld et al. 2014; Morfeld et al. 2016; Ranjeewa et al. 2018; Somgird et al. 2016b; Wemmer et al. 2006), we additionally report means and standard deviations. To compare BCS of different groups, the

Mann-Whitney U test was used. Correlations with quantitative measures were assessed by Spearman's correlation coefficient. This was done for the following parameters: age [years], group size [number of elephants sharing area], amount [all diet amounts are in estimated dry matter] concentrate fed [kg/day], amount bread fed [kg/day], amount fruit fed [kg/day], amount vegetables fed [kg/day], total amount fed (excluding roughage) [kg/day], feeding frequency [feedings/day], feeding enrichment [amount of different devices], amount training [minutes/day], enclosure area indoors [m²], outdoors [m²] and total enclosure area [m²]. More comprehensive evaluation was only performed in Asian elephant females, in which a variety of individual factors were correlated with the BCS; in this case, non-parametric correlations between the significant factors were analysed, and a General Linear Model was performed using ranked data. Statistical procedures were performed in SPSS 23.0.0 (IBM Corp., Armonk, NY), with the significance level set to 0.05.

Results

Collection of pictorial documents

In total, 64 different facilities maintaining 140 African and 228 Asian elephants were visited (all by CS), and elephants were photographed on site between beginning of January 2016 and the end of March 2017. Together with photographs received by

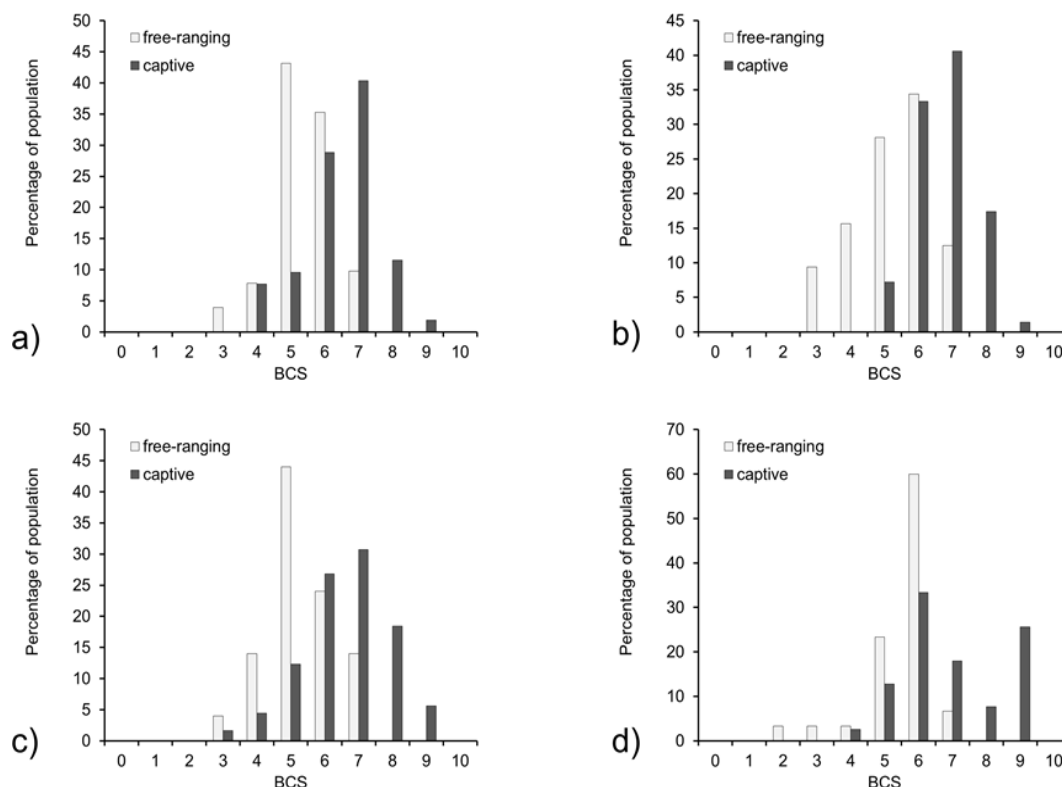


Figure 4. Distribution of body condition scores in populations of free-ranging (n=163) and captive (n=326) Asian elephants (*Elephas maximus*). a) Calves (<5 years), b) Juveniles (5–15 years), c) Adult females (>15 years), d) Adult males (>15 years)

mail, 192 African and 326 Asian elephants of European zoos were included in this study. This sample consisted mainly of elephants participating in the EEP's (470/518; 91%), but elephants of non-member facilities (48/518; 9%) were included as well.

Life history data collection

Documentation and availability of life history and husbandry data varied considerably between institutions. As expected, comprehensive husbandry data were received only during on-site visits. Forty of the 64 visited facilities had a scale to weigh their elephants, and 35 of them conducted weight monitoring on a regular basis. Seven institutions had established body-condition scoring protocols, but only four of these zoos documented body scores with photos. While some facilities applied individual diet sheets for each elephant, others did not have any written document at all and it was up to the keepers how much of which ingredient was fed. Most institutions had some guidelines, which could be adapted by the keepers. Females were monitored much more closely for reproductive status than males, and most facilities used hormonal monitoring via urine or fecal testing. Only two institutions were found to accurately document musth behavior in their males. Investigation of potential correlation patterns between BCS and specific pathologies was not possible due to the diversity in the extent of available medical records.

Data analysis and check for repeatability

The intra-observer agreement generated identical scores in 366 cases (366/500; 73.2%) and a variance by 1 score in 132 cases (132/500; 26.4%). Thus, the repeatability in the range of maximally 1 scoring point was given in 99.6% of the pictures, which was considered acceptable for a protocol with a scoring range from 0 to 10.

Statistical analysis

Body condition scores, their distribution for the European zoo elephant population as well as both free-ranging samples are compiled in Tables 1 and 2 and Figures 3 and 4. Compared to their free-ranging counterparts, elephants kept in European zoos showed significantly higher scores ($P < 0.05$). This was valid for all sex and age categories with the exception of adult African elephant males, in which the difference was marginally below the level of significance ($P = 0.054$).

Within the captive population, there were significant species differences for all age classes; males (Asian mean: 6.21 ± 0.98 , median: 6.00, range: 4–8 vs. African mean: 6.77 ± 0.75 , median: 7.00, range: 6–7; $P = 0.032$), females (Asian mean: 6.58 ± 1.29 , median: 7.00, range: 3–9 vs. African mean: 6.88 ± 1.19 , median: 7.00, range: 1–9; $P = 0.024$), calves (Asian mean: 6.59 ± 0.98 , median: 7.00, range: 4–9 vs. African mean: 7.15 ± 0.69 , median: 7.00, range: 6–8; $P = 0.045$), but not for juveniles (Asian mean: 6.73 ± 0.89 ,

Table 3. Nonparametric correlation of husbandry parameters with body condition in African elephants (*Loxodonta africana*) kept in European zoos

Parameter tested	Calves (<5 years)	Juveniles (5–15 years)	Adult females (>15 years)	Adult males (>15 years)
Age [years]	R=0.14 ; P=0.660; n=13	R=-0.10; P=0.487; n=49	R=-0.00; P=0.968; n=108	R=0.19; P=0.410; n=22
Group size [n elephants sharing area]	n.a.	R=-0.09; P=0.715; n=20	R=-0.16; P=0.104; n=108	n.a.
Amount concentrate [kg*/day]	n.a.	R=-0.12; P=0.535; n=31	R=0.12; P=0.389; n=58	R=0.22; P=0.443 n=14
Amount bread [kg*/day]	n.a.	R=-0.18; P=0.339; n=31	R=-0.27; P=0.042; n=58	R=-0.16; P=0.593; n=14
Amount fruit [kg*/day]	n.a.	R=0.34; P=0.061; n=32	R=-0.02; P=0.899; n=58	R=0.33; P=0.250; n=14
Amount vegetables [kg*/day]	n.a.	R=0.21; P=0.255; n=32	R=0.13; P=0.334; n=58	R=0.10; P=0.733; n=14
Total amount diet (excluding roughage) [kg*/day]	n.a.	R=-0.01; P=0.956; n=32	R=0.12; P=0.382; n=58	R=0.17; P=0.574; n=14
Feeding frequency [feedings/day]	n.a.	R=-0.23; P=0.258; n=27	R=-0.26; P=0.051; n=56	R=-0.35; P=0.266; n=12
Feeding enrichment [amount of different devices]	n.a.	R=0.03; P=0.874; n=32	R=-0.20; P=0.117; n=64	R=-0.57; P=0.034; n=14
Amount training [minutes/day]	n.a.	R=-0.25; P=0.188; n=30	R=-0.06; P=0.632; n=61	R=0.34; P=0.250; n=13
Enclosure area indoors [m ²]	n.a.	R=0.45; P=0.041; n=21	R=-0.10; P=0.453; n=61	R=-0.13; P=0.697; n=11
Enclosure area outdoors [m ²]	n.a.	R=0.13; P=0.477; n=33	R=0.02; P=0.891; n=73	R=-0.19; P=0.502; n=15
Total enclosure area [m ²]	n.a.	R=0.20; P=0.405; n=20	R=0.03; P=0.841; n=57	R=-0.16; P=0.635; n=11

n.a.=not analyzed (n too low); in bold: significant correlations (P<0.05); * estimated dry matter

Table 4. Nonparametric correlation of husbandry parameters with body condition in Asian elephants (*Elephas maximus*) kept in European zoos

Parameter tested	Calves (<5 years)	Juveniles (5–15 years)	Adult females (>15 years)	Adult males (>15 years)
Age [years]	R=0.32; P=0.024; n=49	R=-0.22; P=0.073; n=69	R=0.09; P=0.258; n=179	R=-0.19; P=0.318; n=29
Group size [n elephants sharing area]	n.a.	R=-0.56; P=0.002; n=28	R=-0.22; P=0.003; n=179	n.a.
Amount concentrate [kg*/day]	R=-0.12; P=0.649; n=17	R=0.01; P=0.915; n=63	R=0.08; P=0.337; n=135	R=0.15; P=0.495; n=23
Amount bread [kg*/day]	R=0.11; P=0.674; n=17	R=0.06; P=0.629; n=63	R=-0.06; P=0.491; n=140	R=-0.07; P=0.754; n=24
Amount fruit [kg*/day]	R=0.29; P=0.259; n=17	R=0.386; P=0.002; n=63	R=0.10; P=0.239; n=139	R=0.44; P=0.032; n=24
Amount vegetables [kg*/day]	R=-0.11; P=0.672; n=17	R=0.07; P=0.623; n=60	R=0.20; P=0.018; n=139	R=0.47; P=0.023; n=23
Total amount diet (excluding roughage) [kg*/day]	R=0.04; P=0.871; n=17	R=0.09; P=0.489; n=63	R=0.07; P=0.428; n=141	R=0.32; P=0.122; n=24
Feeding frequency [feedings/day]	R=0.52; P=0.029; n=18	R=0.28; P=0.058; n=48	R=0.03; P=0.771; n=78	R=0.36; P=0.166; n=16
Feeding enrichment [amount of different devices]	R=0.31; P=0.177; n=21	R=0.34; P=0.018; n=49	R=-0.05; P=0.587; n=102	R=-0.17; P=0.492; n=19
Amount training [minutes/day]	R=-0.17; P=0.467; n=20	R=0.05; P=0.762; n=43	R=-0.12; P=0.255; n=93	R=0.37; P=0.136; n=18
Enclosure area indoors [m ²]	R=0.08; P=0.742; n=21	R=0.05; P=0.679; n=62	R=-0.24; P=0.002; n=161	R=-0.24; P=0.243; n=26
Enclosure area outdoors [m ²]	R=-0.11; P=0.620; n=23	R=-0.18; P=0.155; n=67	R=-0.23; P=0.003; n=165	R=0.01; P=0.955; n=28
Total enclosure area [m ²]	R=-0.12; P=0.603; n=22	R=-0.13; P=0.317; n=62	R=-0.27; P=0.001; n=161	R=-0.02; P=0.949; n=26

in bold: significant correlations (P < 0.05); *:estimated dry matter

median: 7.00, range: 5–9 vs. African mean: 6.45±0.71, median: 6.00, range 5–8; P=0.061). Within species, there was no significant difference in BCS according to management system or the origin of elephants (wild caught vs. captive born) for any of the species/age groups. There were no significant differences between male and female adults within either species (data not shown). In neither species did scores differ between females that were cycling, pregnant, lactating or non-cycling. Additionally, we found

no correlation between lactation status and BCS (data not shown). Breeding and non-breeding males of either species did not differ in BCS. However, in Asian adult females, currently breeding females (defined as having at least one offspring during the past 5 years or being currently pregnant) had significantly lower BCS (n=44, mean: 6.18±1.33, median: 6.00, range 3–9) than non-breeding females (n=108, mean: 6.71±1.25, median: 7.00, range 3–9; P=0.021). No such difference was observed in African females

Table 5. Comparison of body condition score distribution in recent population-wide assessments of North American and European zoo elephants

Morfeld et al. (2016) North American population (mean age: 31.1 ± 13.7 years)						Present study European population (mean age: 34.9 ± 11.3 years)					
	African elephant (n=132)		Asian elephant (n=108)		Total		African elephant (n=130)		Asian elephant (n=218)		Total
Scoring range: 1-5	Female	Male	Female	Male		Scoring range: 0-10	Female	Male	Female	Male	
	n=106	n=26	n=85	n=23	n=240		n=108	n=22	n=179	n=39	n=348
Score	Percentage					Score	Percentage				
1	0	0	2.3	0	0.8	0-2	0.9	0	0	0	0.3
2	0	3.8	5.9	8.7	3.3	3-4	0.9	0	6.1	2.6	3.7
3	21.7	38.5	16.5	26.1	22.1	5-6	32.4	45.5	39.1	46.2	38.2
4	45.3	50.0	27.1	47.8	39.6	7-8	64.8	54.5	49.1	25.6	51.7
5	33.0	7.7	48.2	17.4	34.2	9-10	0.9	0	5.6	25.6	6.0

($P=0.619$). Similarly, adult Asian females living in a breeding group had significantly lower BCS ($n=98$, mean: 6.39 ± 1.31 , median: 6.00, range: 3–9; $P=0.022$) than those not living in a breeding group ($n=81$, mean: 6.82 ± 1.25 , median: 7.00, range 4–9). Again, no such difference was evident in African females ($P=0.941$), or juveniles of either species. There were neither significant differences between non-breeders and previous breeders, nor between current and

previous breeders, and there was no significant difference in any group depending on whether animals were weighed or BCS was applied regularly or not (data not shown). Results of non-parametric correlation tests between BCS and husbandry parameters are presented in Tables 3 and 4. For the African species, BCS in juveniles was positively correlated with indoor area, while for adult females and males, there was a significant

Table 6. Overview of research conducted on body condition scoring in African elephants (*Loxodonta africana*)

Living conditions	n	Investigated sex/age categories [years] ± SD	Standardized average score (average score/scoring range)	Correlating Parameters	Reference
free-ranging	240	all ages of both sexes	-	season	Albl (1971)
free-ranging	22	adult males only	-	stage of musth	Poole (1989)
free-ranging	not indicated	reproductively active females only	0.56-0.80 (mean)	season	Foley et al. (2001)
free-ranging	4-107 (depending on season and category)	all age classes females only	0.40-0.70 (mean)	season, nutritional resources, lactation	De Klerk (2009)
free-ranging	544	adults only	-	season, sex, history of translocation	Pinter-Wollman et al. (2009)
free-ranging	57	females only (10-45 years)	0.60 (median)	-	Morfeld et al. (2014)
free-ranging	124	all age classes of both sexes	0.56 (mean); 0.55 (median)	-	this study
semi-captive _a	7	juveniles of both sexes ; 10.7 ± 2.8	0.83 (mean and median)	-	Velthuisen (2008)
captive _b	not indicated	all age classes of both sexes	0.60 (mean)	handling method	Harris et al. (2008)
captive _c	50	females only (10-45 years)	0.80 (median)	captivity	Morfeld et al. (2014)
captive _c	132	both sexes, age not separately indicated for species	0.80 (mean and median)	sex, walking exercise, feeding schedule & methods	Morfeld et al. (2016)
captive _c	20	females; 34.75 ± 8.17	0.77 (mean); 0.80 (median)	age, body mass, fat mass	Chusyd et al. (2018)
captive _d	189	adults of both sexes; 30.7 ± 8.4	0.62 (mean); 0.64 (median)	-	this study

captive: investigated animals live in captivity; semi-captive: investigated animals live in semi-captive conditions in countries of origin; free-ranging: free-ranging individuals were investigated, a: elephant training facility in South Africa; b: UK zoos; c: North American zoos; d: European zoos

Table 7. Overview of research conducted on body condition scoring in Asian elephants (*Elephas maximus*)

Living conditions	n	Investigated sex/age categories; mean age [years] \pm SD	Standardized average score (average score/scoring range)	Correlating parameters	Reference
free-ranging	-	not indicated	-	-	Fernando et al. (2009)
free-ranging	653	calves, juveniles, sub-adults and adults of both sexes	-	season, faecal glucocorticoid metabolites	Pokharel et al. (2017)
free-ranging	1622	calves, juveniles, sub-adults and adults of both sexes	-	season, sex	Ramesh et al. (2011)
free-ranging	27	not indicated	0.60 (median and mean)	-	Wijeyamohan et al. (2015)
free-ranging	3175 (containing 526 individuals at different times)	adult females, sub-adult and adult males	0.51 (mean)	reservoir water level, sex, age-size class in males	Ranjeewa et al. (2018)
free-ranging	163	all age classes of both sexes	0.49 (mean); 0.45 (median)	-	this study
semi-captive _a	119	All age classes of both sexes; age known for 50 elephants: 17.5 ± 1.8	0.61 (mean)	-	Wemmer et al. (2006)
semi-captive _b	42	all age classes of both sexes; 20.6 ± 17.7	0.35 (mean)	-	Harris et al. (2008)
semi-captive _c	22	mature females only; 29.4 ± 9.9	0.73 (mean and median)	-	Thitaram et al. (2008)
semi-captive _c	5	adult males only; 41.4 ± 13.1	0.63 (mean); 0.75 (median)	-	Somgird et al. (2016a)
semi-captive _d	9	adult males only; 58.4 ± 8.6	0.69 (mean); 0.75 (median)	age, duration of musth Phase	Somgird et al. (2016b)
captive _e	140	all age classes of both sexes; 37.4 ± 1.4	0.58 (mean and median)	sex	Godagama et al. (1998)
captive _f	not indicated	all age classes of both sexes	0.58 (mean)	handling method	Harris et al. (2008)
captive _g	12	not indicated	0.69 (median)	rump fat thickness	Treiber et al. (2012)
captive _h	12	adults and juveniles of both sexes; 34.0 ± 15.6	0.60 (mean); 0.68 (median)	-	Kumar et al. (2014)
captive _i	10	adult and juvenile females of both sexes; 37 ± 19.93	0.57 (mean); 0.55 (median)	-	Romain et al. (2014)
captive _g	31	not indicated	0.80 (mean and median)	captivity	Wijeyamohan et al. (2015)
captive _g	108	both sexes, age not separately indicated for species	0.81 (mean); 0.8 (median)	sex, walking exercise, feeding schedule and methods	Morfeld et al. (2016)
captive _j	326	adults of both sexes; 37.6 ± 12.0	0.60 (mean); 0.64 (median)	captivity, breeding state, diet, enclosure size	this study

negative correlation of BCS with the amount of bread in the diet and the amount of feeding enrichment provided, respectively. In the Asian species, BCS in calves was positively correlated with age and feeding frequency. Juveniles and adult males showed both a positive correlation between BCS and amount of fruit in the diet, which also occurred for the amount of vegetables in the diet of adult females and males. Body condition scores in adult females were negatively correlated with the size of indoor, outdoor and total area.

Focusing on the various individual factors yielding a significant association with BCS in Asian females, group size was negatively correlated with the amount of vegetables fed ($R=-0.50$, $P<0.001$, $n=139$), and positively with living in a breeding group ($R=0.79$, $P<0.001$, $n=179$), being a breeder ($R=0.38$, $P<0.001$, $n=179$), and total enclosure area ($R=0.23$, $P=0.002$, $n=179$). Similarly, the total enclosure area was negatively correlated with the amount of vegetables fed ($R=-0.29$, $P=0.001$, $n=136$), positively with living in a breeding group ($R=0.51$, $P<0.001$, $n=161$) and positively with



Figure 5. Challenges encountered while scoring zoo elephant's body condition: a) extraordinary hairiness, b) excessive hyperkeratosis, c) voluminous belly and d) well developed musculature

being a breeder ($R=0.28$, $P<0.001$, $n=161$). Using ranked data for BCS, the amount of vegetables fed and total enclosure area, a General Linear Model with BCS as dependent variable, group size, vegetables and area as covariates and living in a breeding group as a cofactor yielded a significant association with (ranked) total enclosure area only ($F=11.320$, $P=0.001$), whereas neither group size ($F=0.187$, $P=0.666$), the amount of vegetables fed ($F=2.636$, $P=0.107$) nor living in a breeding group ($F=0.216$, $P=0.643$) were significant.

Discussion

Reflection of our method

Data collection on site resulted in more comprehensive data especially concerning diet composition and management system than data collection via mail contact. Pictures of elephants taken by the author fulfilled the criteria to be included in 100% of the cases, whilst nearly 3.5% (5/150) of elephants for which pictures were received remotely did not pass this selection and were excluded from the study. Thus, elephants living in visited zoos might be overrepresented in our analysis. Ideally each elephant-keeping facility across Europe should have been visited, which was not feasible due to temporal and financial limitations. With

respect to the data on the diets, it needs to be noted that amounts were based on the facilities' estimates of the amounts fed and not on actually measured intake data.

It can be questioned whether visual body condition scoring allows a reliable assessment of an elephant's fat storage, because this method cannot consider intraabdominal adipose deposits. A recent study in horses detected a strong positive correlation between BCS and retroperitoneal fat score whilst no association between BCS and mesenteric or epicardial fat was found (Morrison et al. 2017). Whether this assumption is valid for elephants, too, will be hard to prove due to the lack of a method that allows assessment of intraabdominal fat deposits in a non-invasive way.

Although recommended as a management tool (Ward et al. 1999) and confirmed as viable by studies conducted in various species including elephants (Joblon et al. 2014; Morfeld et al. 2014; Morfeld et al. 2016; Pérez-Flores et al. 2016; Pettis et al. 2004; Pokharel et al. 2017; Wijeyamohan et al. 2015), BCS based on photographs has several limitations. First of all, standardisation regarding light conditions, ground planarity, movement and angle of the camera can be reached only to a certain extent. This limitation has been reported in cattle (Bewley et al. 2008) and might be even more pronounced in our work with respect to the significant variability between elephant-keeping facilities.

In order to reach the highest standardisation possible, the formulation of several criteria, which a photograph had to fulfill to be included in the study together with a strict selection process, were of paramount importance. During the scoring process two unexpected cases occurred, which led to the exclusion of further photographs. These were extraordinary hairiness and excessive hyperkeratosis in the lumbar region, prohibiting reliable scoring (Figures 5a and b).

Compared to the generally accepted protocol by Wemmer et al. (2006), our method focused on fewer body regions. However, these areas correlate strongest with subcutaneous measurements respectively serum triglyceride levels as indicators of fat storage in elephants (Albl (1971), Morfeld et al. (2014; 2016).

Individual animals have unique body proportions and fat distributions (Clements and Sanchez 2015), which may influence BCS and complicate comparisons between individuals. This aspect also seems valid in elephants, and consistent scoring was influenced by variance in an elephant's individual appearance in many cases. This was especially true for elephants with a very voluminous belly or a prominent thoracic spine, where a vigilant effort was required to remain focused on the lumbar region (Figure 5c). Additionally, the visual scoring approach can hardly discriminate subcutaneous fat and well-developed musculature, which became obvious in elephant males (Figure 5d). Awareness of the musculoskeletal anatomy may reduce this limitation but cannot completely eliminate it. For pet species a muscle condition score (MCS) has been developed to be used complementary to body weight and BCS (Michel et al. 2011; Santarossa et al. 2017). Such systems are based on palpation, which would be impractical in elephants due to their size, thick skin and frequent inaccessibility. Nevertheless, we consider the scoring approach applied here to allow a reasonable ranking of animals.

The scoring of elephant calves represented another challenge. As mentioned before, the applied protocols have not been investigated concerning their applicability in sub-adult elephants. To our knowledge, no comparative research has been conducted in this field yet. Wijeyamohan et al. (2015) report their method to be applicable in elephants independent of sex and age, albeit they do not provide any evidence supporting this recommendation. Although our scoring method turned out to be independent of age, and the overall pattern of a difference between free-ranging and captive animals was also reflected in the calf data (Tables 1 and 2), we remain skeptical whether BCS can be meaningfully applied to growing animals. More insight in the validity of visual BCS in calves and juveniles might be gained by the comparison with growth curves. Hence, a long-term scoring approach combined with weight data would be more informative than our cross-sectional approach.

It remains unanswered how overweight, obesity and the ideal condition in elephants should be defined. For their 10-point scale, Wijeyamohan et al. (2015) do not define which score range is ideal. Morfeld et al. (2014; 2016) define score 3 in their 5-point scale as "ideal/normal", while Treiber et al. (2012) consider a score from 4 to 7 in their 9-point scale preferable. Consequently for the scale applied here ranging from 0 to 10, a BCS between 4 and 6 could be considered ideal. These definitions are only based on the assumption that the middle range of an index represents a preferable condition. It should be noted that our data on free-ranging elephants indeed suggests that a BCS in the middle of the range, or slightly above it, appears to be the "normal" (Tables 6 and 7).

Scores of European zoo elephants

As intended, data collection and consequent scoring led to a comprehensive overview on BCS of the European zoo elephant population. Our goal to evaluate each zoo elephant in Europe

was nearly reached with the evaluation of 97% (518/534). Similar to current results from North America, the majority of European zoo elephants in both species had elevated BCS with 57.7% of the population in the scoring range of 7–10. This percentage is lower compared to the results from North America (73.8%, Table 5).

Relation to findings from previous research

Comparing the average proportions of scoring ranges of individual studies, six studies conducted on African elephants in (semi-) captivity revealed consistently standardised scores of at least 0.6, including three reports with a mean/median of at least 0.8 of the score range. In contrast, research on free-ranging African elephants demonstrated in four out of four cases values of maximally 0.6, with two reports showing higher scores exceptionally during seasons with high primary productivity (De Klerk 2009; Foley et al. 2001). Thus, our findings are in accordance with the literature in reporting higher scores in captive compared to free-ranging African elephants (Table 6).

In nine out of 13 studies investigating Asian elephants in (semi-) captivity, the mean/median BCS was >0.6 of the score range, whereas data on free-ranging Asian elephants reported by Wijeyamohan et al. (2015) and Ranjeewa et al. (2018) had a mean/median of 0.6 respectively 0.51 and our results do not even reach 0.5 (mean: 0.49 and median: 0.45). Our study thus corroborates findings from the literature with higher scores in captive compared to free-ranging populations of the Asian elephant (Table 7).

For wild elephants, body condition scores are affected by seasonal changes in resource availability (Foley et al. 2001; Pokharel et al. 2017; Ranjeewa et al. 2018; De Klerk 2009). Using a sample originating from one of the most extensively studied and best protected elephant populations across Africa, namely in Amboseli National Park, we tried to prevent an overestimation of the difference between captive and free-ranging conditions. Amboseli elephants do fluctuate in body condition but this environment is much less extreme than other habitats, and score changes in a normal (non-drought) year are considered to be minimal (Amboseli Elephant Project, long term data). Similarly, we used a sample from the long-term studied population in Yala National Park for the Asian species.

It is unknown whether the difference in BCS between free-ranging and captive elephants is principally caused by a calorific oversupply or by lack of physical activity. The amount and quality of zoo diets are usually not season-dependent and are more energy-rich compared to natural foods, which might predispose zoo elephants for higher BCS (Hatt and Clauss 2006). Although we cannot explain the negative correlation of BCS with amount of bread fed to female African elephants, the positive correlation of BCS with the amount of fruits and vegetables fed to adult and juvenile Asian elephants supports the above-noted assumption (Table 4). Moreover, the influence of an unnatural energy-rich diet on body condition has been reported in further wildlife species (Heidegger et al. 2016; McWilliams and Wilson 2015; Scheun et al. 2015; Wright et al. 2011). Walking distance in some zoo elephants has been shown to be similar to the situation in the wild (Holdgate et al. 2016; Rowell 2014) although there might be considerable variation between facilities. Results from previous research in the UK and North American zoo population did not reveal any correlation of BCS with daily walking distance (Harris et al. 2008; Holdgate et al. 2016). We were not able to detect a correlation of BCS with staff-directed exercise, as reported by Morfeld et al. (2016). Due to the trend for a shift from direct contact to protected contact in European zoos (EEG 2017), only a few facilities remain that practice staff-directed walking of their elephants. However, a correlation of BCS with management system could also not be detected. This finding corroborates results from North America (Morfeld et al. 2016), but is in contrast

to Harris et al. (2008) who reported significantly lower scores for UK zoo elephants managed in free contact. Authors of the latter study do not hypothesise whether this correlation might be caused by staff-directed exercise. In adult Asian elephant females we detected a significant negative correlation of BCS with enclosure size (Table 4). This correlation was not found by Morfeld et al. (2016), but may support the intentions of modern zoos to build larger facilities to further improve elephant welfare. To investigate the influence of such measures in a proper way, a long-term study regarding the development of BCS over time would be more appropriate than our cross-sectional approach applied here. Compilation of comprehensive health data would be important to allow the investigation of potential correlation patterns regarding zoo elephant welfare.

The significantly higher scores found in African elephants compared to their Asian counterparts in European zoos have not been reported yet. Harris et al. (2008) and Morfeld et al. (2016) did not find any difference in BCS between the two elephant species. In contrast to the recent study of the North American zoo population by Morfeld et al. (2016), we could not find any significant correlation between BCS and sex. Neither did differences correlate with reproductive or lactation status. According to findings from previous research in free-ranging populations (Albl 1971; De Klerk 2009; Ramesh et al. 2011), significant differences depending on reproductive and lactation status were expected. Their absence is in accordance with the report from Thitaram et al. (2008) and can be explained by additional nutritional supply of lactating females in captivity, which might cover their increased needs and maintain a stable condition, or the inappropriateness of our cross-sectional study design to detect BCS changes over the course of lactation. On the other hand, we found significantly lower scores in currently breeding adult Asian females compared to non-breeders, and the difference was also significant when all females living in a breeding group (regardless of whether or not the individual animal was breeding) were considered. Such a result would in theory match previous findings in African elephants (Freeman et al. 2009; Morfeld and Brown 2016), black rhinoceros (*Diceros bicornis*) (Edwards et al. 2015) and Asian greater one-horned rhinoceros (*Rhinoceros unicornis*) (Heidegger et al. 2016) that females with a higher body condition score have a lower reproductive viability. However, the finding of Freeman et al. (2009) of a positive correlation of a body mass index (kg/m²) used as indicator of physical condition with the risk to be acyclic in captive African elephant females was not corroborated in either species in the present investigation, which is in accordance to the findings of Chusyd et al. (2018). The interrelationships between breeder status, group size, diet and enclosure size in the present study did not allow identifying a simple causation. Leighty et al. (2009) suggested social complexity and breeding to increase walking rates in zoo elephants, which might explain lower BCS in larger groups that breed and have larger enclosures at their disposal. However, enclosure area might be a surrogate measure for the general investment (in terms of various resources) and other management measures that lead to positive effects for elephant BCS.

Although no indicators of health status have been shown to correlate with BCS in captive elephants yet (Miller et al. 2016), foot disorders and degenerative joint disease in (older) elephants should in theory be exacerbated by high BCS, as suggested by Fowler and Mikota (2006). In other species, reduced longevity and life quality of obese individuals is documented, such as orangutans (*Pongo spp.*) (Cocks 2007), pet dogs (Yam et al. 2016) as well as humans (Samaras and Elrick 2002). Additionally, Heidegger et al. (2016) suggest the occurrence of leiomyomas in captive female greater one-horned rhinos to be linked with obesity; these authors also review some of the pertinent literature for humans.

It would be interesting to assess whether this is also true in Asian elephants that often suffer from uterine leiomyoma (Aupperle et al. 2008; Lueders et al. 2010; Sanchez et al. 2004), and which role a potential gene mutation reported in humans may play (Heinonen et al. 2014).

These considerations lead to the recommendation that regular monitoring of weight and body condition, and the implementation of measures that maintain an intermediate rather than an obese body condition, are important in captive elephants. This is not only important with respect to their health in general, but as well to successful breeding. Although the latter may be heavily influenced by factors like availability of appropriate males and herd constellations (Töffels 2015; Wiese and Willis 2006), we consider monitoring of female elephant's condition an important cue to increase breeding success, which is in accordance with Freeman et al. (2009). This is especially true for the captive population of African elephants which is not self-sustaining (Schwammer and Fruehwirth 2015; Schwammer and Fruehwirth 2016). In long-lived species such as elephants, long-term monitoring is required to reliably detect factors influencing husbandry success with emphasis on their health and welfare.

In conclusion, validated protocols served as practical tools for population-wide visual body condition scoring of European zoo elephants. In accordance with previous research, zoo elephants of both species had significantly higher BCS compared to samples from free-ranging populations. Compared to current population data from North America, zoo elephants in Europe show a trend towards a more ideal scoring range. A near ideal BCS is an aim to strive for as part of welfare in the husbandry of elephants and as such further improvement regarding the diet are warranted for the captive elephant population. To monitor the influence and effectiveness of such adaptations, visual body condition scoring in a long-term approach might present a reliable tool.

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